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MyHouse

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION

BY

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MYHOUSE

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MYHOUSE

By

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SENIOR DESIGN PROJECT REPORT

Submitted to

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of

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in Partial Fulfillment of the Requirements

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ABSTRACT

Consumers tend to lack an understanding of the way that their electricity is priced and the way that their energy consumption impacts utility operations. In this paper, we create a program and hardware implementation that uses day-before hourly electricity pricing and efficiency modes aiming to better distribute the user's power consumption, control the user's peak power consumption, shave peaks at the hours where electricity costs the most, as well as reduce the user's monthly electricity bill. Our program achieves this by optimizing the operation time of appliances such as the washer, dryer, dishwasher, HVAC, and electric vehicle charging and by managing the operation of a battery to supplement the home's load. Additionally, it shows the user's power consumption as a way of educating the user about utility pricing and their power consumption. Our program and hardware implementation succeeded in reducing a monthly electricity bill for our worst-case heavy-use day by 58.27%. The way that electricity is priced needs to be changed in order to reward people for using electricity at alternate times of the day and to discourage people from contributing to the load demand.

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Acknowledgments

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I. Introduction

For much of the past 60 years, environmental agencies and organizations around the world have been aware of increasing global temperatures caused by increased proportions of carbon dioxide in the atmosphere. The goal for global temperature limitation agreed upon by national governments around the world has long been set to two degrees Celsius – the purported tipping point beyond which global changes will be irreversible. One major part in the global push to limit global temperature rise is limiting carbon dioxide emissions, and perhaps the greatest focus of that push has been energy generation and use.

Due, in part, to government initiatives and improved technology, adoption of renewable energy sources, such as Solar PV and Wind generation, is rapidly increasing as consumers push for cheaper and cleaner electricity. While this is undoubtedly a good development, the first step in grid transition to a sustainable and carbon neutral electricity generation industry, it creates some technological hurdles that must be addressed before renewable energy sources can become the backbone of the power system. With states like California aiming for 100 percent clean energy by 2045, technological or societal fixes for these hurdles must be found quickly.[1] One of the major hurdles in California is that the aggregated electricity demand of the state at peak times, usually 5 to 7 pm, is roughly 1.4 times that of the average demand, increasing rapidly as people get home from work and solar sources go offline for the day. This rapid ramp up creates control issues within the larger grid itself and represents a significant challenge to solar adoption. Due to these issues, the state of California alone curtailed 95,000 MWh of solar energy in April 2018, thus limiting the effectiveness of installed solar and preventing further grid transition.[2] To minimize this, California is currently pushing towards a full state-wide rollout of time-of-use pricing.[3] Time-of-use pricing

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[1] P. Rogers and K. Murphy, "California mandates 100 percent clean energy by 2045," *The Mercury News*, 10-Sep-2018. [Online]. Available: https://www.mercurynews.com/2018/09/10/california-mandates-100-percent-clean-energy-by-2045/. [Accessed: 04-Jun-2019].

[2] J. Temple, "California is throttling back record levels of solar-and that's bad news for climate goals," *MIT Technology Review*, 29-May-2018. [Online]. Available: https://www.technologyreview.com/s/611188/california-is-throttling-back-record-levels-of-solarand-thats-bad-news-for-climate-goals/. [Accessed: 04-Jun-2019].

[3] H. K. Trabish, "California utilities prep nation's biggest time-of-use rate rollout," *Utility Dive*, 06-Dec-2018. [Online]. Available: https://www.utilitydive.com/news/california-utilities-prep-nations-biggest-time-of-use-rate-roll-out/543402/. [Accessed: 04-Jun-2019].

is pricing that is intended to directly correct the current demand curve to fit the shape the utility would like its ideal demand curve to fit – essentially punishing peak usage times with higher prices and incentivizing lower use times with low, even negative, prices.

Problem Statement

Currently due to an oversaturation of solar energy, as solar turns off, a large and rapid increase in the net demand – or the total electrical demand subtracting solar and wind energy contributions – causes control issues in the grid, limiting the amount of solar that can be installed and used. This issue is referred to as the duck curve. Utilities are implementing real-time pricing to help reduce the duck curve, but consumers struggle to schedule their energy use to correspond with real-time pricing curves, causing them to pay more than they ought to for their electricity.

Benefit

MyHouse will allow people to easily and quickly adjust their appliance usage to maximize their savings under real-time pricing without majorly impacting their comfort or ability to use appliances in the order they choose. Without some form of program or technology, it is extremely difficult for consumers to adjust to pricing curves that change daily, particularly when those curves do not have the same shape from day to day. MyHouse provides accurate and user-considerate energy use schedules, considering the projected pricing curve from the utility, the needs of the consumer for that particular day – which the consumer gets to select for themselves – and the specific appliances that consumer possesses. By allowing users to determine the order in which appliances are run, as well as which appliances are run in a given day, MyHouse minimizes its invasiveness in a user's everyday life while providing substantial benefit.

Furthermore, to cater to those not under real-time pricing, MyHouse offers the option to cap peak power usage at any given time – distributing loads throughout the day, thus avoiding the higher pricing bands associated with higher peak energy usage in many pricing schemes.

Existing Solutions

Due to the novelty of this issue, and the cutting-edge nature of time-of-use pricing, there are very few existing residential load management solutions that consider societal impacts, such as the duck curve, or that directly confront the differing effects that energy use has at different hours of the day. That being said, there are some current products that help to either minimize residential energy use or to control different appliances, two of the major aspects of MyHouse. We will address one here.

Nest Learning Thermostat

Nest Learning Thermostat is a product currently on the market which controls and monitors one specific aspect of your house – the atmosphere within it. Unlike a traditional thermostat, Nest constantly monitors the state of your house: the temperature, the humidity, and, most importantly, the activity in front of it, which tells the thermostat whether people are home. By learning when people are typically around the house on a given day of the week, Nest can adjust furnace usage on its own, changing the use of the HVAC system to optimally follow residential patterns; turning off when no-one is around, and turning on just before people typically arrive. Controlling the temperature and humidity of the house in an intelligent way allows Nest to save its users energy on a daily basis, which is undoubtedly reflected on the energy bill every month.

While Nest is a great product, it does have some major limitations. First, it is limited to controlling the temperature and humidity. While saving energy on heating is a massive step forward, much of our daily energy consumption is through high power appliances, such as dryers, washing machines, dishwashers, and electric vehicles. Nest does not address the usage of these appliances, despite their ability to create costly peaks in energy usage. Second, Nest does not consider pricing, a major disadvantage for consumers and society at large, especially as the utility pricing scheme changes to time-of-use rates. Due to its inability to consider these highly priced times, Nest may make poor decisions regarding when to use energy, potentially costing its users significant amounts of money. Finally, Nest is a relatively expensive system to install, with the cheapest available unit being $199 retail[4]. This price for a thermostat is not feasible for many lower income families who, with older, less efficient appliances and less money to pay for their monthly electricity bills, arguably need the smart control and energy use reduction the most.

[4] Nest, "Nest Learning Thermostat | Installation and Tech Specs," *Nest*. [Online]. Available: https://nest.com/thermostats/nest-learning-thermostat/tech-specs/. [Accessed: 04-Jun-2019].

MyHouse aims to solve many of these issues: it will primarily focus on controlling appliances other than the HVAC system, like dryers, washing machines, dishwashers, and electric vehicles, while also considering hourly pricing projections from the utility company in the area – specified to the location of the house in question. By using this information, we can minimize the difficulty users will have following these pricing curves by providing them with easy to follow recommendations for when to use each appliance, given their preferences on order of use. Additionally, MyHouse would ideally be able to be implemented in a relatively cheap format – where these savings would quickly become available to those with lower household incomes.

Project Goals

Our team had four primary goals for MyHouse, each one pertaining to some aspect of either cost savings for users or solutions to residential contributions to the duck curve. Our first, and primary, goal throughout this project was to minimize utility cost to the residents of the house – the users of this product. As, in a fully developed form, a product following this concept would need to convince users to adopt it, we figured that we must give a fiscal reason for its adoption. Thus, we prioritized optimizing appliance use to the pricing curves, which minimizes cost, rather than to the demand curve, which minimizes contributions to the duck curve. In an ideal world, the real time prices would price-signal to reduce duck curve contributions, allowing these two goals to be achieved simultaneously, but currently prices do not correspond well to ideal use hours.

Second, we aimed to minimize or negate household contributions to the duck curve. This was not quite as realistic, as we were eventually forced to choose between the duck curve and cost to consumers, but it was initially a major goal.

Third, we aimed to efficiently use a household battery to peak shave during the costliest hours of the day. This was important as ideal residential battery use is difficult to maintain for most houses. Without an intelligent system charging and discharging the battery during ideal hours to optimize savings for the consumer, it is nearly impossible to charge and discharge ideally.

Fourth, and finally, we aimed to control peak energy use. This is important due to the current pricing model most utilities follow – putting a home into a pricing 'band' based upon their peak power demand, then multiplying their total energy consumption by that set rate to set their bill for the month. As such, we wanted to allow consumers to choose their band by dictating how much power could be maximally used in a given hour.

Project Description

MyHouse is an in-house control program prototype designed to manipulate the timing of appliance usage to minimize cost using day-ahead pricing curves provided by regional utility authorities to calculate ideal use hours for the appliances. The list of appliances used each day, and the order in which they are run, is set by user input on any given day. We used a variety of models to fully simulate the energy usage of each of these components, modelling the HVAC system, household battery, electric vehicle, dryer, dishwasher, and washing machine. The HVAC system was modeled on the thermodynamic approximation of a 1600 square foot house, while the household battery and electric vehicle were modeled using a discrete, state-space model we developed. Other appliances were modeled using average values. After taking these inputs, MyHouse outputs the energy use each hour, the appliances run each hour, and the total price of the energy use for the day.

II. System

Appliance Models

When we were looking at which appliances to model in our system, the primary criteria that we used was energy consumption, and controllability. Many homes now have a plethora of electronics and we wanted to focus our attention on the appliances that used the most energy. In a common household. When looking at the controllability of appliances, we considered which appliances that we could schedule operation times with minimal interference in the user's daily life. This was extremely important because one of the goals for MyHouse is to create additional convenience for the user. MyHouse would have no hope of being integrated into people's homes if it interfered with the way that people go about their lives. It is for this reason that refrigerators, electric water heaters, and electric ranges are not controlled by MyHouse despite consuming significant amounts of energy. The refrigerator needs to always be on, and users need to be able to sleep and eat at their own convenience. That being said, we did take those appliances into consideration when creating the baseload for our model. In the end, we ended up controlling the washer, dryer, dishwasher, as well as the electric vehicle charging which will be discussed later on.

We modeled our appliances by taking into consideration the power that they consume as well as the duration of their operation time. Figure 1 displays the wattage values that we used to model our appliances and table 1 displays the operation time of each of the washer, dryer, and dishwasher that we used.

TABLE 10.1 Annual Energy Requirements of Electric Household Appliances

Appliance	Average Wattage	Est. kWh Consumed Annually[a]
Food preparation		
Coffeemaker	1,200	140
Dishwasher	1,201	165
Egg cooker	516	14
Frying pan	1,196	100
Mixer	127	2
Oven, microwave (only)	1,450	190
Range, with oven	12,200	596
Toaster	1,146	39
Laundry		
Clothes dryer	4,856	993
Washing machine, automatic	512	103
Water heater	2,475	4,219
Quick recovery type	4,474	4,811
Comfort conditioning		
Air conditioner (room)	860	860[b]
Dehumidifier	257	377
Fan (circulating)	88	43
Heater (portable)	1,322	176
Health and beauty		
Hair dryer	600	25
Shaver	15	0.5
Sunlamp	279	16
Home entertainment		
Radio	71	86
Television, color, tube type	240	528
Solid-state type	145	320
Housewares		
Clock	2	17
Vacuum cleaner	630	46

a) Based on normal usage. When using these figures for projections, such factors as the size of the specific appliance, the geographical area of use, and individual usage should be taken into consideration. Note that the wattages are not additive, since all units are normally not in operation at the same time.

b) Based on 1000 hours of operation per year. This figure will vary widely depending on the area and the specific size of the unit. See EEI-Pub #76-2, "Air Conditioning Usage Study," for an estimate for your location.

Source: Edison Electric Institute.

Figure 1: Appliance Models[5]

Table 1: Appliance Operation Time Duration

Appliance	Operation Time Duration (hours)
Washer	0.5
Dryer	1
Dishwasher	2

After the hours of the day have been sorted from lowest to highest in terms of electricity cost each appliance that is ran is added to the baseload. Adding the washer and dryer to the base load proved to be the simplest case for us as our program looks at price by hour and the dryer only runs for one hour so we simply added the energy consumption of the dryer to the hour of operation. For the

[5] J. W. Nilsson and S. A. Reidel, *Electric Circuits Analysis*, 9th ed. Boston, MA: Prentice Hall, 2011.

washer, we had our program run it for a half of an hour. When running the dishwasher, we added the energy consumption of the dishwasher to the base load during the selected operation start time for one hour, and then added the energy consumption of the dishwasher to the next hour.

Battery and Electric Vehicle Models

In our program, we treat the electric vehicle and the battery very similarly because as far as the load is concerned, an electric vehicle behaves identically to a very large battery that needs to be charged. We based our battery model off of the Tesla Powerwall with a total capacity of 14 kWh, a round trip efficiency of 90%, and a maximum charge and discharge rate of 5 kW[6]. The round-trip efficiency is the product of the charging and discharging efficiencies. In our model we made the assumption that the charging and discharging efficiencies were the same, so we took the square root of 0.9 resulting in a value of 94.8% that we used for our charging and discharging efficiencies. For the electric vehicle, we based our battery size off the 2013 Tesla Model S with a 60-kwh battery back[7]. For the charging efficiency of our electric vehicle, we used an efficiency of 86.9% and a charging power of 20 kW[8][9]. The only difference that exists between the way that we treated the battery and the electric vehicle is that My House only models the electric vehicle as a load. Although papers have been published regarding the usage of an electric vehicle to supplement a home's energy consumption, that functionality was not included in My House. That is because this feature does not currently exist in electric vehicles and because doing this would charge and discharge the vehicle more often. This is an issue because batteries have finite life spans and we do not want to shorten the lifespan of the electric vehicle battery because its primary purpose is to serve as transportation.

We implemented discrete state space equations to model the charging function of the electric vehicle and battery and the discharging function of the battery. We used a discrete implementation because this is easy to integrate into digital systems. When the battery is charging, it receives the power delivered to the battery multiplied by the charging efficiency. When the battery is

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[6] "Tesla Powerwall 2 Datasheet."
[7] "Compare Side-by-Side," *Fuel Economy*. [Online]. Available: https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=32557&id=33612&id=33367&id=33368. [Accessed: 04-Apr-2019].
[8] N. Kong, "Exploring Electric Vehicle Battery Charging Efficiency," rep.
[9] "TESLA WALL CONNECTOR, 8OA SINGLE PHASE INSTALLATION MANUAL." .

discharging, the power that the load receives is the power discharged by the battery multiplied by the discharging efficiency. In our implementation of the state equations, the battery state of charge is converted to kW-min and the functions are executed in minute time-steps. This was necessary because the MyHouse algorithm runs on an hourly basis and the conversion needed to be made within the code so that the battery could charge and discharge more precisely. The relationship between the battery and the load is shown below[10].

<u>Charging:</u>

$$SOC(t+1)=SOC(t)+P(t)*\eta \qquad (1)$$

$$BASE(t+1)=BASE(t)+P(t) \qquad (2)$$

<u>Discharging:</u>

$$SOC(t+1)=SOC(t)-P(t) \qquad (3)$$

$$BASE(t+1)=BASE(t)-P(t)*\eta \qquad (4)$$

SOC: state of charge (kWh)
BASE: baseload (kWh)
P: power (kW)
η: efficiency

When operating batteries, constraints are very important on the battery state of charge because it helps preserve the battery's health. The batteries used for energy storage and electric vehicles are lithium ion batteries that have lives that are a fixed amount of cycles. A cycle is defined as charging and discharging a battery completely. Constraints are placed on the battery state of charge in order to maximize the battery's lifespan. When the battery charges, lithium ions flow from the cathode to the anode. When the battery discharges, lithium ions flow from the anode to the cathode. This bit of information is significant because not only do the cathodes and anodes contain the ions, but the ions also support the structure of the anode and cathode. If a battery is allowed to charge or

[10] L. Chandra and S. Chanana, "Energy Management of Smart Homes with Energy Storage, Rooftop PV and Electric Vehicle," 2018 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), Bhopal, 2018, pp. 1-6.

discharge too much, one the electrodes collapses and the other expands. Allowing the electrodes to expand or collapse too much is bad for the battery life because it creates a lot of mechanical stress on the electrode structures causing the battery to deteriorate resulting in reduced performance. Due to these considerations, we decided to constrain our batteries' state of charge from 15 to 90 percent of the total battery capacity.

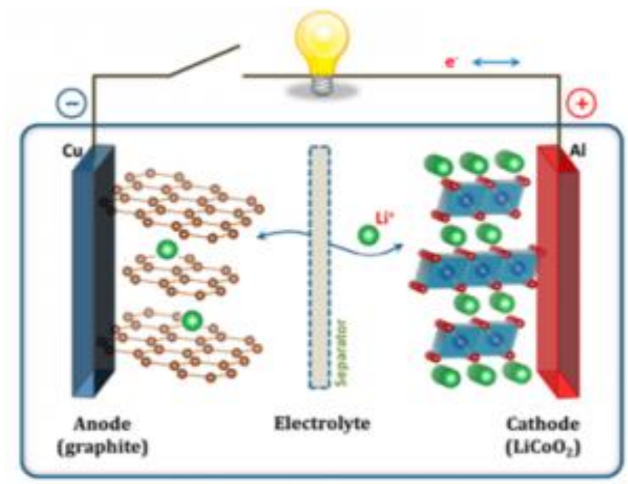

Figure 2: Physical Model of Battery

Solar Model

Within the MyHouse model we included a model of solar panel energy production because they are becoming a quintessential part of the modern home and a key element in a sustainable future. For our model, we were going to simulate the energy output of a 5-kW solar panel array because that is the size of the typical solar panel array[11]. We wanted to take hourly solar measurements with a small 42-watt solar panel that we had available in the Latimer Lab. Using the data that we found from these measurements, we planned on scaling our data to simulate the output of fifteen spr-s21-335-blk solar panels by sunpower each rated at 335 watts resulting in a total output of 5.025 kW[12]. We intended to take measurements with the solar panel facing south at 38 degrees for

11 "PG&E Guide to Going Solar."
12 "SUN POWER X-SERIES RESIDENTIAL SOLAR PANELS SUPPLEMENTARY TECHNICAL SPECIFICATIONS." .

the best position during different weather conditions[13][14]. Unfortunately, we ran into the problem that the small solar panels that we had access to were not compatible with the PV analyzers that we had in the lab and as a result we were not able to accurately measure the power output of the solar panels through the duration of the day. We needed to find another way to gather solar data. To model our data, we found the CAISO website has records of the renewable energy production for every day of the year[15]. We ultimately ended up drawing data from February 8, 2019, April 17, 2019, August 10, 2018, and October 23, 2018 because they reflect the different weather patterns of each season. We then normalized this data with respect to the 5-kW solar panel array energy output for our simulation. The only issue that we encountered with using this data is that it fails to capture the way positioning and angle impact the power output of the solar panel array. The numbers and graphs of the solar energy production used in our simulation are located in the appendix.

Thermal Model

The thermal model of the house is important for our system as it functions as a base load. Essentially since people generally keep their house heated to the same temperature throughout the day. This means that the energy consumption of the heating, ventilation, and air conditioning unit, or HVAC, is not constant, and is generally not flipped on and off like the washing machine and dryer. In order to do this, we took an existing model in Simulink and edited it in order to make it representative of a 1614.59 square foot (150 square meter) house. We assumed that the system was 100% efficient since much of the data around efficiency ratings for ac systems is not directly related to how much wattage is necessary to cool down the air, and the fact that heaters are 100% efficient.

[13] J. Marsh, "Best Solar Panel Angle by Zip Code in 2019 | EnergySage," *Solar News*, 04-Oct-2018. [Online]. Available: https://news.energysage.com/whats-the-best-angle-for-my-solar-panels/. [Accessed: 04-Apr-2019].
[14] R. Fares, "So What Direction Should Solar Panels Face?," *Scientific American Blog Network*, 21-Oct-2014. [Online]. Available: https://blogs.scientificamerican.com/plugged-in/so-what-direction-should-solar-panels-face/?redirect=1. [Accessed: 04-Apr-2019].
[15] "Renewables and emissions reports," California ISO - Renewables and emissions reports. [Online]. Available: http://www.caiso.com/market/Pages/ReportsBulletins/RenewablesReporting.aspx. [Accessed: 16-Apr-2019].

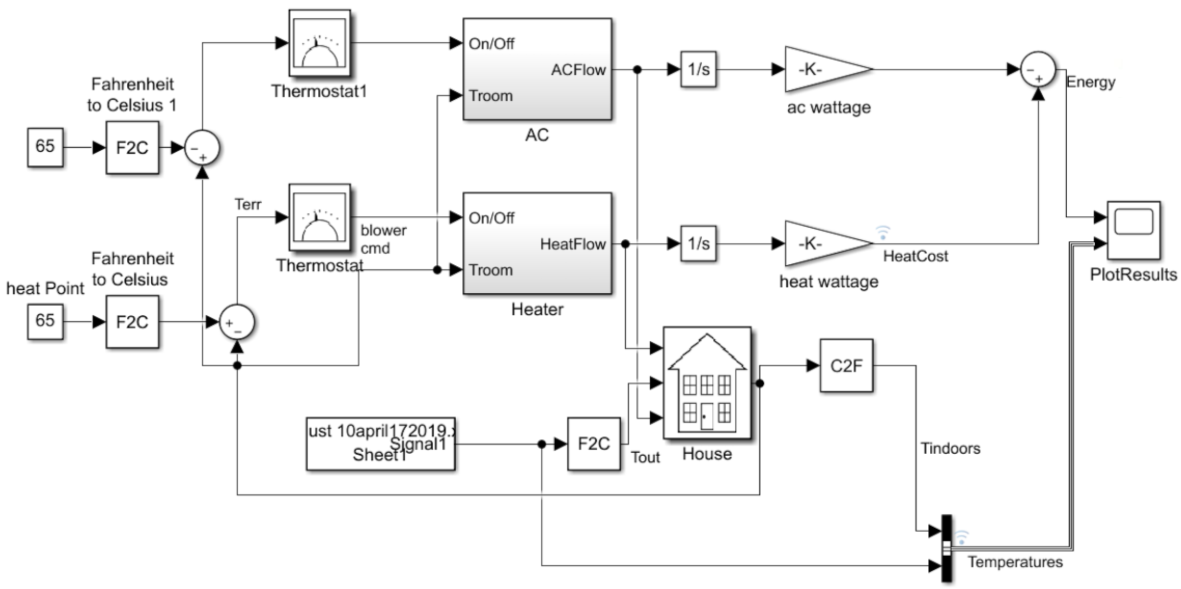

Figure 3: HVAC Model

The model uses a comparator to decide whether turn on the air conditioning or the heat. When the heater is turned on, the temperature in the room is subtracted from the temperature of heater and then multiplied by the mass flow rate of the air (3600 kg/h). The air conditioning system functions exactly the same but has a value of 10 degrees Celsius.

$$\frac{dQ}{dt} = (T_{heater} - T_{room}) \cdot \frac{dM}{dt} \cdot c \tag{5}$$

$$\frac{dQ}{dt} = heat\ flow\ from\ the\ heater\ into\ the\ room$$

$$c = heat\ capacity\ of\ air\ at\ constant\ pressure$$

$$\frac{dM}{dt} = air\ mass\ flow\ rate\ through\ the\ heater$$

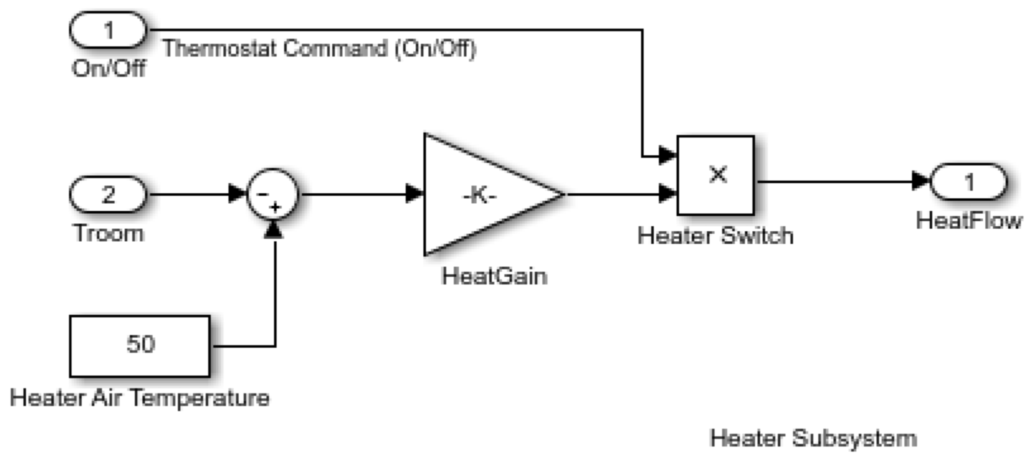

Figure 4: Heater Model

The heat flow calculated is then fed into the house model which can be seen in figure 5.

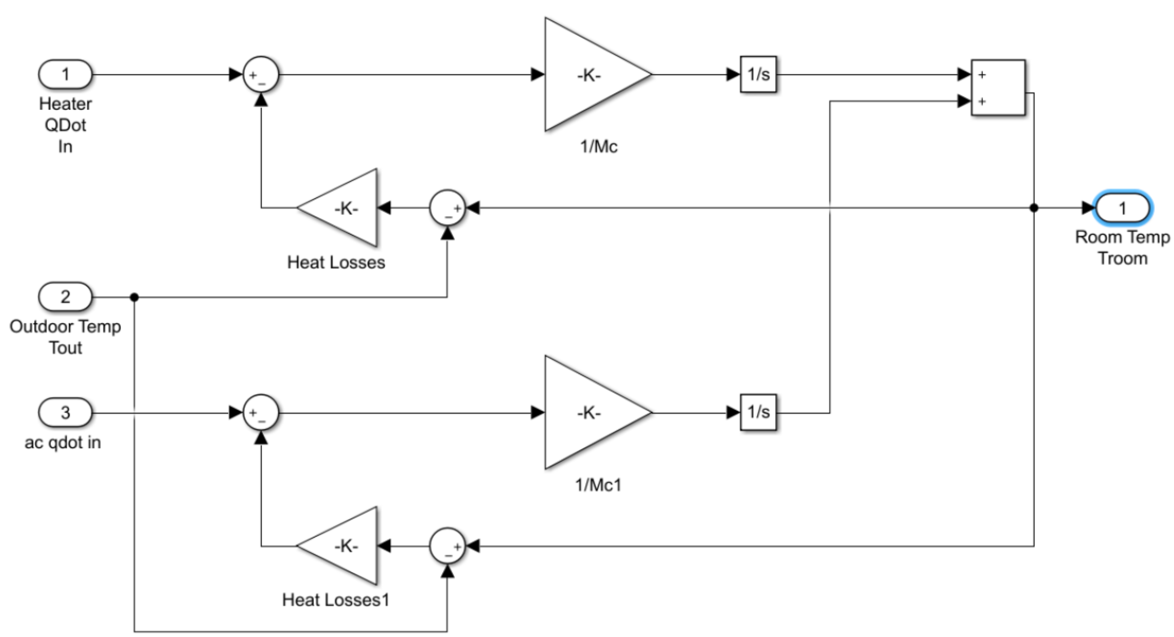

Figure 5: Thermodynamic Model of House

Here the outdoor temperature is subtracted by the current room temperature, and then divided by the thermal resistivity of the house in order to account for heat losses. The thermal resistivity of the house was calculated by dividing the thickness of the wall by the product of the surface area of the wall and the thermal conductance of the insulation[16]. This was repeated for the windows of the house and the two resistances were then added together like two parallel resistors resulting in a final value of 5.390498×10^{-6}. The heat losses are then subtracted from the heat flow and multiplied by the mass of air in the room in order to get the change in temperature in the room, which is then integrated in order to get the new temperature of the room.

$$\frac{dQ_{losses}}{dt} = \frac{(T_{heater} - T_{room})}{R_{eq}} \tag{6}$$

$$\frac{dT_{room}}{dt} = \frac{1}{M_{air} \cdot c} \cdot \left(\frac{dQ_{heater}}{dt} - \frac{dQ_{losses}}{dt}\right) \tag{7}$$

$$M_{air} = Mass\ of\ air\ inside\ the\ house$$

$$R_{eq} = equivalent\ thermal\ resistance\ of\ the\ house$$

Figure 6 shows an example of the system running on a summer day, specifically August 10th of 2018. The energy usage is in green and shows the total amount of energy used up until that point in the day. The outdoor temperature (blue) is shown on the same graph as indoor temperature (red). Both graphs are on the same time scale in order to show the correlation between the energy usage and the associated temperatures. The outdoor temperature data is based on readings from the San Jose International Airport[17], and four different dates were used in order to represent each of the four seasons and the associated graphs can be found in the appendices .Essentially the energy consumed increases when the temperature is further away from the set point. The energy usage is then fed into our MyHouse system in order to function as a baseload.

[16] "Thermal Conductivity of common Materials and Gases," *Engineering ToolBox*. [Online]. Available: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html. [Accessed: 04-Jun-2019].

[17] "San Jose, CA History," *Weather Underground*. [Online]. Available: https://www.wunderground.com/history/daily/us/ca/san-jose/KSJC/date/2019-5-20. [Accessed: 04-Jun-2019].

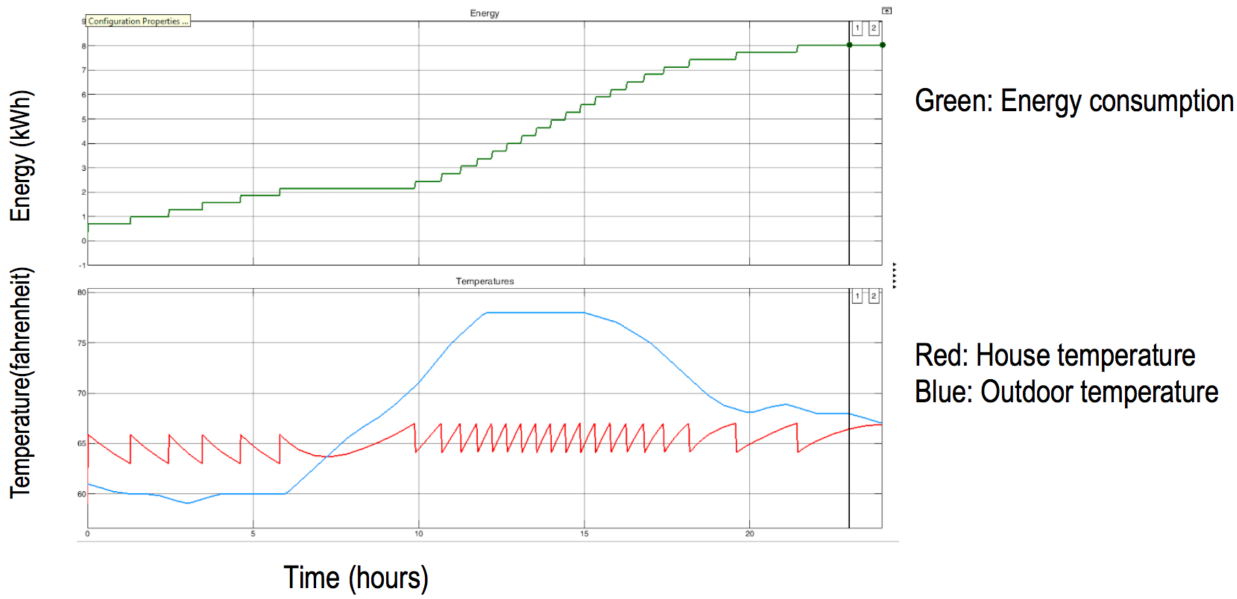

Figure 6: Energy Consumption and Temperature 8/10

Base Load

The base load that we used in our model consisted of four primary components. These components were the energy consumption of the HVAC system, the energy production of the solar panel array, the refrigerator, and various non-controllable appliances inserted through the duration of the day to make our load more accurately represent what it would look like in a home where the residents are living there and consuming non-controllable electronics and appliances. These appliances would include the electric range, toaster, hair dryer, television, and coffeemaker[18]. Additionally, we created base loads for each of the four seasons using the data from the solar panel output and the HVAC energy consumption.

Pricing

An important feature to distinguish MyHouse from other products on the market was the implementation of determining when to run appliances from current prices. This task required us to understand how the energy market operates. The cost of power is determined based on the location the energy is being distributed within and the time of day the energy is being sold at. The prices are calculated two different way: day-ahead pricing and dynamic pricing. The price of

[18] "Samsung 24.6 Cu. Ft. French Door Refrigerator with Thru-the-Door Ice and Water Stainless steel RF263BEA ESR," Best Buy. [Online]. Available: https://www.bestbuy.com/site/samsung-24-6-cu-ft-french-door-refrigerator-with-thru-the-door-ice-and-water-stainless-steel/4980442.p?skuId=4980442. [Accessed: 17-Apr-2019].

energy is always changing due to fluctuations of when companies need it, the availability of renewable energy, and other unpredictable events. Due to the variations, MyHouse want to eliminate any uncertainty of when a user should run appliances through implementing a price sorting feature to determine when appliances should be running. As these prices are defined based on location, we looked through all of the pricing nodes in the Santa Clara area, eventually landing on node CSCGNRA1_7_N001 which can be seen in the figure below.

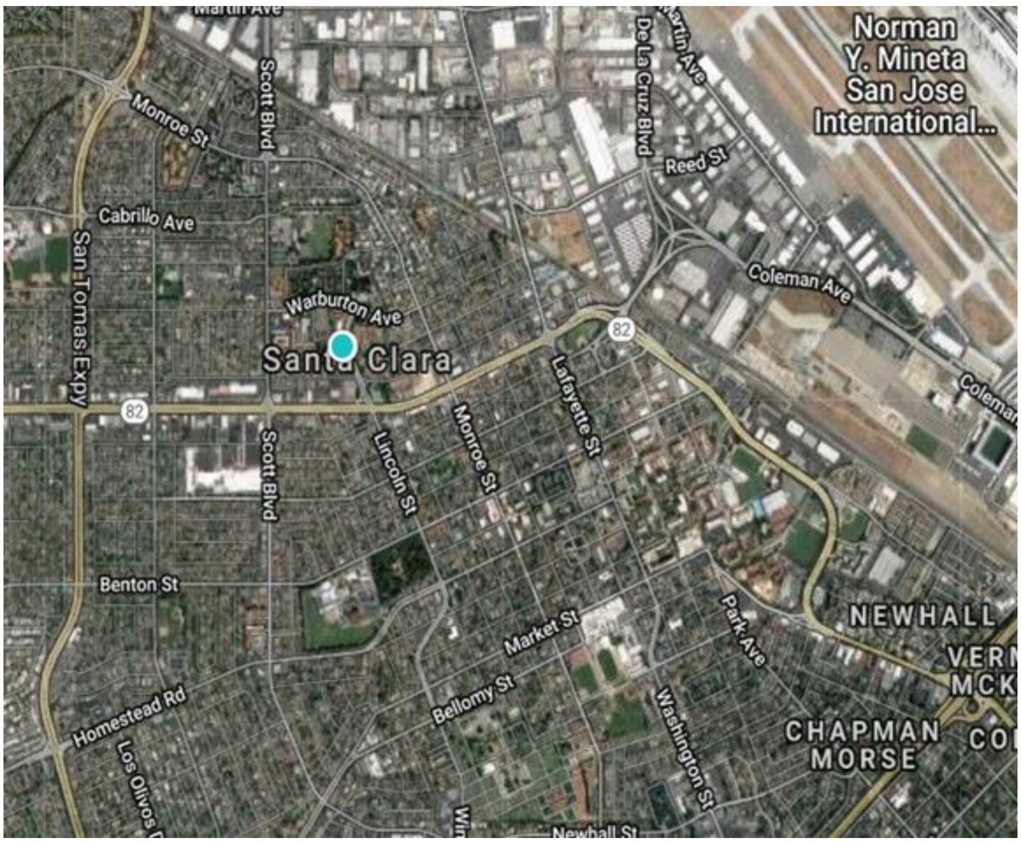

Figure 7: CAISO Node CSCGNRA1_7_N001[19]

Initially the intention was to get MyHouse to obtain the real-time prices, but we elected to use the day-ahead prices simply because the estimations were generally fairly accurate, and it enabled our system to plan when to run appliances for the next 24 hours. The day-ahead pricing is obtained from a comma-separated value (csv) file. From the csv file we read in the hours and the price of energy obtained from the location. We were able to obtain the csv file from the California

[19] "Market price maps," *California ISO - Price Map*, 06-May-2019. [Online]. Available: http://www.caiso.com/PriceMap/Pages/default.aspx. [Accessed: 06-May-2019].

Independent System Operator (CAISO) website.[20] CAISO oversees several different elements of California's energy production including the energy market. From this CSV file, the times and prices are taken and sorted in ascending order for time. Once the times are correctly formatted the times were sorted to be in chronological order and an index was used to sort the prices in the same order. This step allowed for the time, prices, solar, and base readings to all be in the same order. From here the price is sorted from least to most expensive and an index is created to enable MyHouse to place the time, solar, and base readings in their correct locations. The pricing curves generated by the raw data used in this analysis can be seen in the figure below.

Figure 8: Price Comparison Month to Month

Once sorted appliances will operate during the inexpensive hours and stored power generated from solar panels during the day is used to power the expensive hours. This usage data is fed back and used to determine the ideal time for the battery to be charged and discharged.

[20] "Oasis Location Marginal Price Database," OASIS Prod. [Online]. Available: http://oasis.caiso.com/mrioasis/logon.do. [Accessed: 04-Jun-2019].

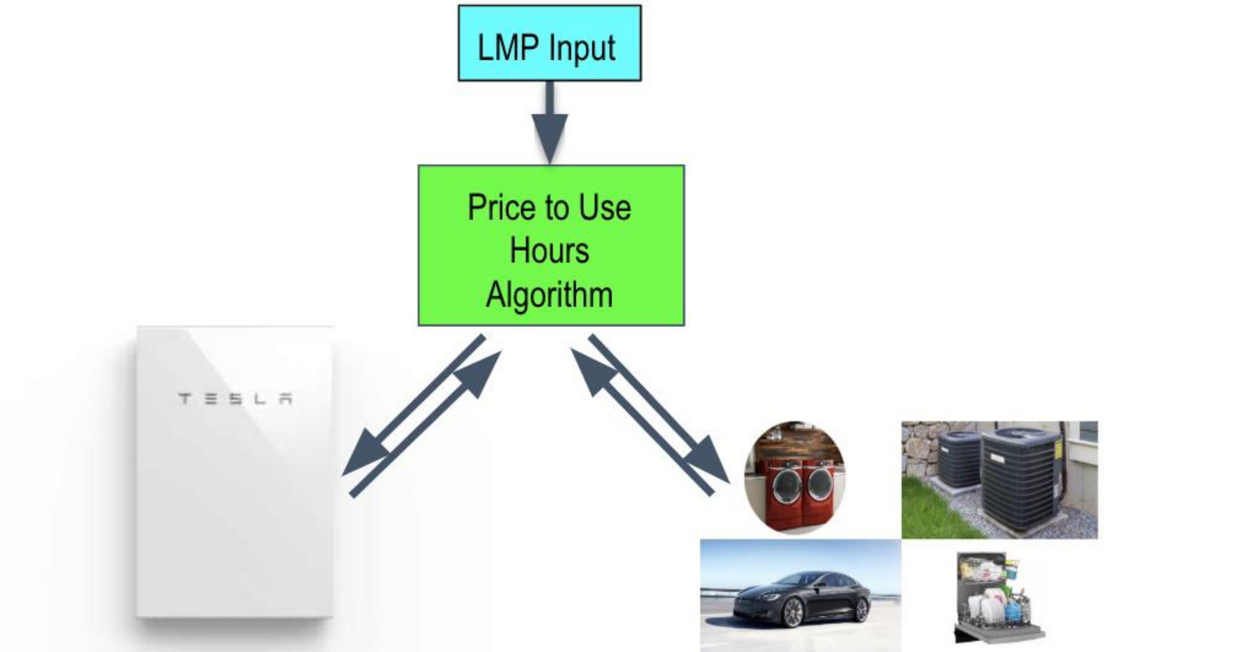

Figure 9: Appliance and Price Interaction Flowchart

Decision Making

MyHouse takes into consideration several different inputs when it comes to deciding when to run a given appliance. Two of the inputs are non-user defined and rely entirely on values pulled the CAISO website to determine the prices over the 24-hour period as well as the solar readings, which help us determine the quantity of the photovoltaic cells that can be converted into solar energy. There are two other inputs which are decided by the user and play an important role in how MyHouse decides what appliance to run and when. Users must first enter in the peak power mode they want the MyHouse to run on. Users are given three options on how efficiently they want to run their appliances: Low, Medium, and High. These options create a ceiling for the amount of power a user can consume over a given hour. The low option enables users to run all of their appliances at once whereas the medium and high options will spread the appliances run over the times where the prices is also low.

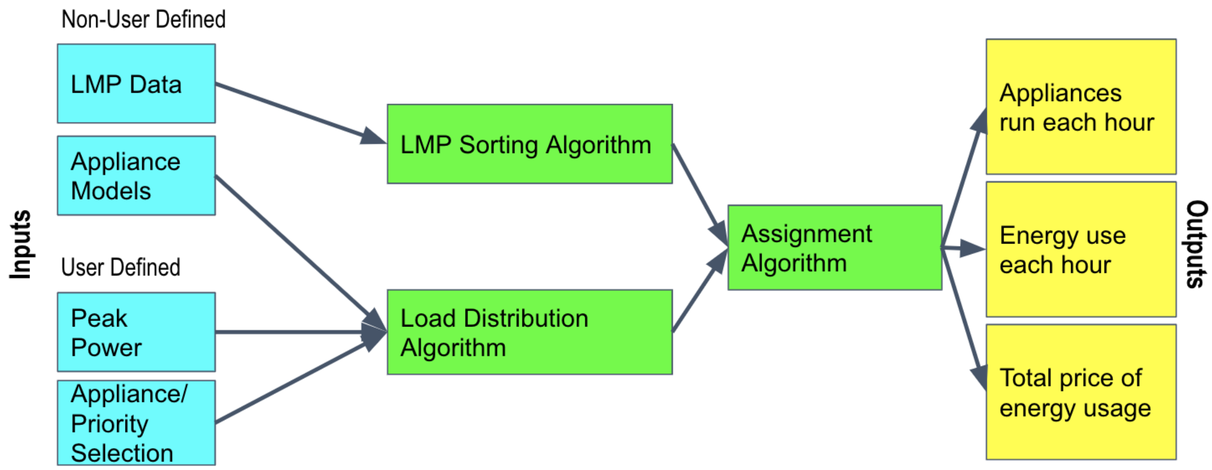

Figure 10: MyHouse Algorithm Flowchart

The other input users are able to control is the order the appliances are run in. Users are able to choose and prioritize which appliance they want to be run. Users are simply prompted to enter in the appliance they want to run first and to continue entering appliances in the order of preference. The appliances' energy consumption is added to the load if the peak power mode allows for the appliance to run. If the peak power mode does not allow for the appliance to run at the least expensive hour, it will progress down and run the appliance at the least expensive hour that can handle running the appliance. If no time is able to handle running the appliance, MyHouse will alert the user they cannot run the appliance at their given peak power mode.

Testing

MyHouse was put through a variety of tests in order to make the software was running properly. We tried to recreate scenarios that seemed feasible for the average household to utilize through the day. This actually leads to an interesting issue. The differences between the price for using MyHouse compared to the price of not using MyHouse showed minimal difference. This led to implementing a total price savings throughout a month. Implementing the total price savings throughout a month helps the users notice the impact the software has towards saving money.

Furthermore, we carried out a systematic testing protocol of the software component of MyHouse, testing its functionality with 9 different daily pricing curves, and a variety of potential user inputs. These pricing curves covered every season, and had different magnitudes and shapes, yet

MyHouse was able to successfully adapt to each of them. Some of these curves are shown in figures 8 (earlier in the document) and 11 (below). We primarily focused on curves from days in the spring - particularly those that had just happened - as working with more contemporary and real time data allowed us to see how the program would operate in a real residential use scenario.

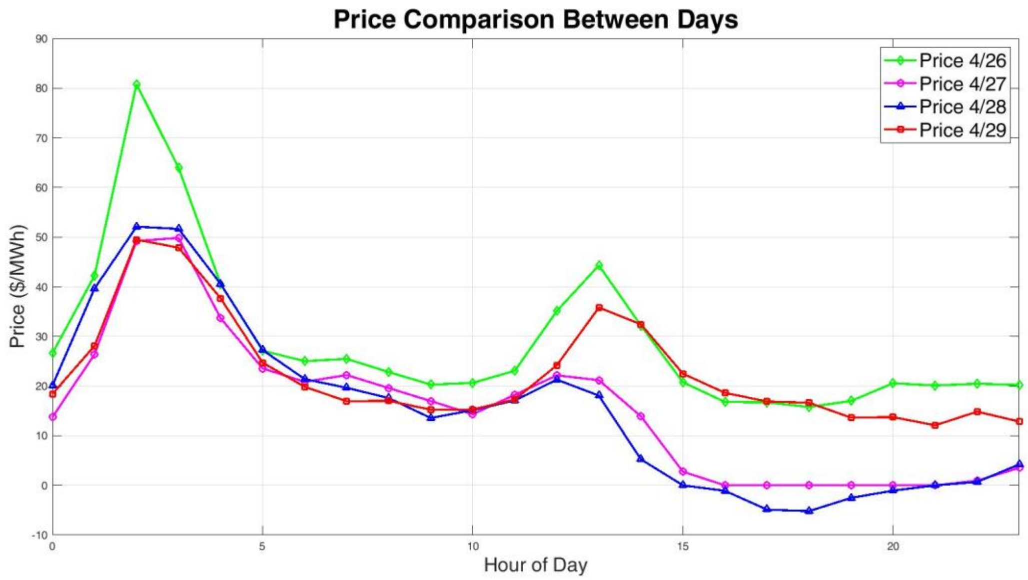

Figure 11: Pricing Curve Comparison Day to Day

As load distribution is only difficult with many appliances to distribute, we primarily focused on testing heavier load distributions, varying the order, which appliances ran, and the number of times each appliance ran. While there is a limit to how many appliances we could run in a day and stay below our set peak power values, MyHouse performed well in every test we gave it in its final iteration. While occasionally it would have issues handling certain orders, this was mainly due to our failure to consider the impact of those orders - i.e. trying to discharge the battery when it's already empty. As these were the only major issues we ran into during testing, we felt that MyHouse passed our systematic testing and was ready to be used.

Raspberry Pi

MyHouse has been implemented onto a Raspberry Pi. This microcontroller has both Bluetooth and WiFi capabilities as well as several useful pins that can be used to read values into Python and Simulink programs. Having access to WiFi enables MyHouse to eventually be able to download the prices from CAISO. Being able to communicate via Bluetooth will allow communication between smart appliances and also appliances using a smart plug. Bluetooth also offers a secure way to communicate between the devices and reduces the risk of hackers gaining control of the appliances. Using the I2C pin, the temperature values can be obtained from a temperature sensor. Using the temperature sensor allows for the house to maintain an ideal temperature through giving the HVAC system the inputs of whether or not the house needs to be heated or cooled.

In order to make MyHouse run on the Raspberry Pi, it has been modified - translated from Matlab to Python in order to interact well with the Raspberry Pi’s internal software. Additionally, some components have been translated into Simulink blocks to run more smoothly. Everything, from the user input to the temperature data, can now be run through the Raspberry Pi, meaning that this has the potential to be turned into a true Smart Home product. A potential implementation of how MyHouse could operate in the future can be seen in figure 12.

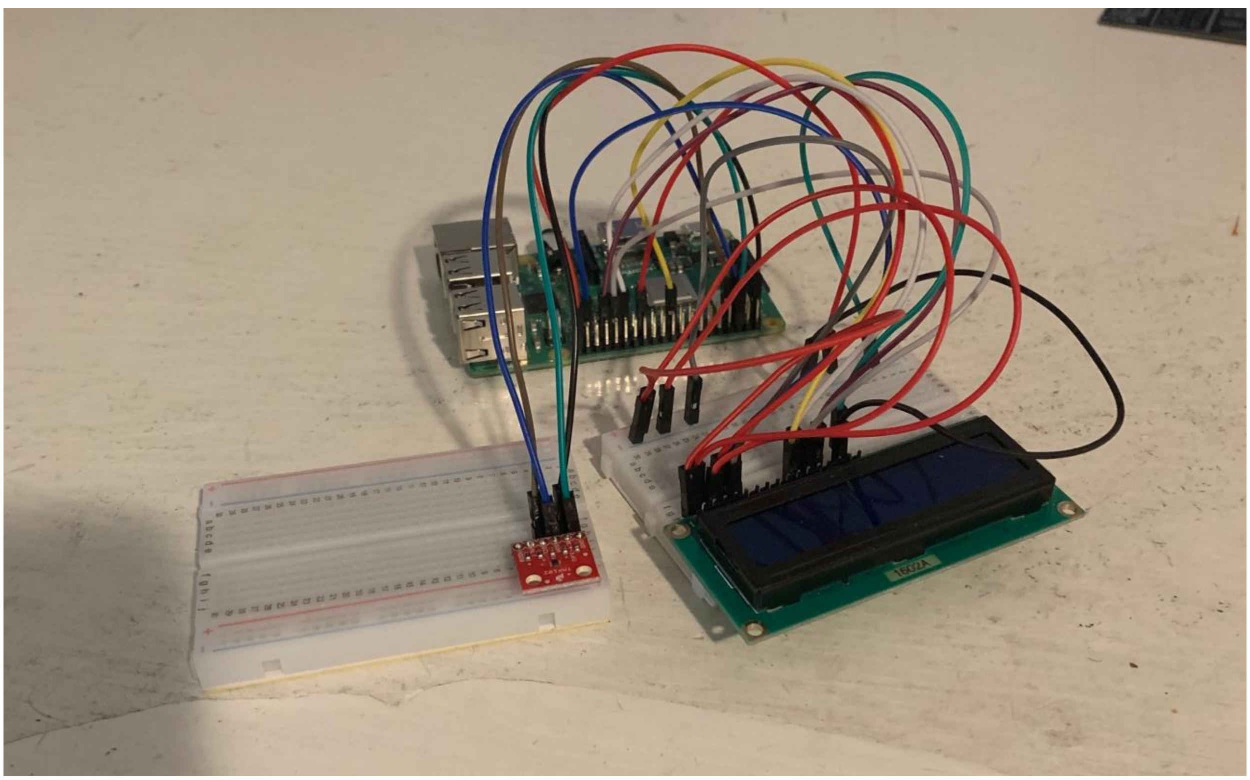

Figure 12: Raspberry Pi Implementation

Results

MyHouse was successful in accomplishing its technological aims, being able to take a variety of inputs and pricing data and ideally distribute the appliance run times in every scenario, improving on base “typical” use cases for every set of inputs. As the variety of potential input permutations are essentially endless, we have selected two specific cases to review in this section: a heavy use case during the summer and during the winter. We have chosen these particular inputs to examine here as they cover the extremes of the range of possible inputs and seasons, showing the limits of MyHouse programmatically. Heavy loads are the most difficult to distribute, thus we have focused on these distributions in this examination.

We made a few assumptions during these example runs – first and foremost that the occupants of our simulated household, and thus the car, would be home all day and thus available to charge at any given time. This assumption simplifies our simulation significantly, especially as it is difficult to generalize hours in which the car will not be home during the day. In a real product, this assumption could be done away with by implementing learning software which would sense when the car is at home, and thus be able to create daily profiles for typical car use, scheduling charging hours around that profile. Secondly, we assumed that the loading and unloading of appliances was not an issue. In a real world case, this would be dealt with by the user and would hopefully not result in loads of laundry being run twice, or not being transferred from washer to dryer in time.

Heavy Optimized Case: Summer

In the optimized heavy case, we dictated the various user inputs to the program. We used the solar and base load data that we calculated for summer, in order to show the effect of high demand for energy from the air conditioning and strong solar energy contribution on the MyHouse optimized load distribution for a particular day. For this test, we used pricing data from April 24th, as it had a pricing curve very similar to the typical pricing curve for a summer day, despite being in the spring. Additionally, we chose to cap the peak power usage at 30 kW, our middle value. We chose this particular value in order to allow the car charger to run as it requires 20 kW at any given time, but still limit the peak power usage of other appliances.

The user set appliance order we chose for this particular test went as follows: washer, dryer, dishwasher, car charging, washer, dryer. This order was chosen in order to simulate the real world order in which one would use their appliances; in this case washing and drying one load of laundry, then washing a load of dishes, charging the car, then running a second load of laundry. Additionally, we set the battery to discharge and charge over the course of the day at ideal times. The resulting energy usage curve for this particular day simulation is shown below in figure 13.

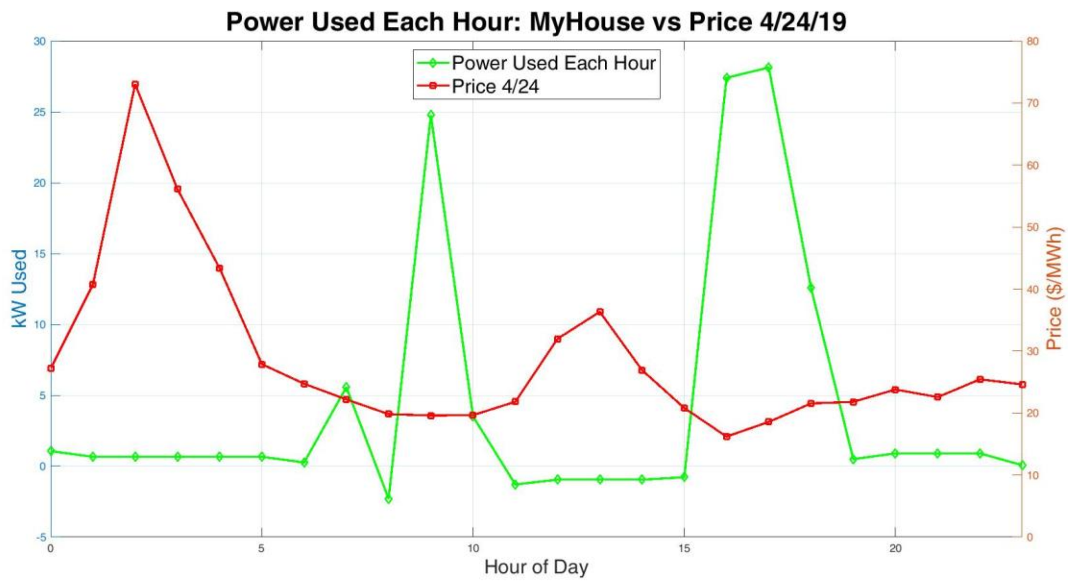

Figure 13: MyHouse Heavy Load Simulation, Summer

In this particular test, we can see that the highest use hours correspond directly to the lowest price hours of the day, the sole exception being the uncontrollable base case spike at 7 am. Additionally, no single hour has greater than 30 kW being used at a given time, indicating that MyHouse abided by the peak power requirement dictated. Each appliance was run in the order dictated by the user inputs. The hourly breakdown is as follows: from 9 to 10 am, the car charged one third of the way and the washer ran. From 10 to 11 am, the dryer ran. From 4 to 5 pm, the car charged and the dishwasher and washer ran. From 5 to 6 pm, the car charged, the dryer ran, and the battery discharged. From 6 to 7 pm, the battery recharged. This particular test day used 99.33 kWh of energy from the grid, roughly our expected value for the maximal use of a house in one day.

From this distribution, we can also calculate the total cost of this energy usage for the house per day, and over the course of a 30 day month. For this heavy load case with MyHouse optimization, the total cost per day came out to $1.97 per day, or $59.19 per month.

Heavy Optimized Case: Winter

To test the effects of seasonality on the results of MyHouse optimization, we ran identical user inputs through the system, with the base load, solar input, and pricing curve changed to mimic typical winter values. This is reflected in significantly decreased solar input, increased base load due to higher energy demand from the heater, and significantly higher energy prices across the board. The resulting energy usage curve can be seen in figure 14.

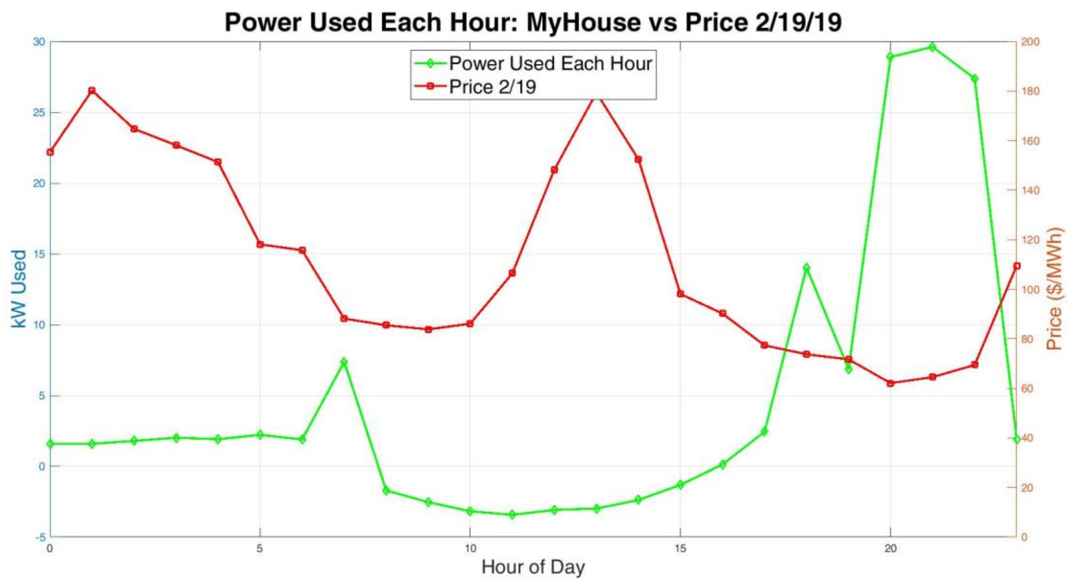

Figure 14: MyHouse Heavy Load Distribution: Winter

In this simulation, we can see that the highest use hours again correspond to the lowest priced hours, with the battery again discharging to minimize cost and shave a major peak. Again, the peak power stayed below 30 kW, showing that the distribution algorithm works to peak-shave. Each appliance was again run in the order dictated by the user inputs. The hourly breakdown is as follows: from 6 to 7 pm, the washer ran, the dryer ran, the dishwasher ran, and the battery discharged. From 8 to 9 pm, the car was charged and the washer ran. From 9 to 10 pm, the car and battery charged. From 10 to 11 pm, the car charged. This test day used 111.0168 kWh of energy, roughly our expected value for the maximal use of a house in one day during the winter.

From this distribution, we can also calculate the total cost of this energy usage for the house per day, and over the course of a 30-day month. For this heavy load case with MyHouse optimization during the winter, the total cost per day came out to $12.53 per day, or $375.89 per month.

Base Cases

In order to calculate exactly how much we saved users compared to an uncontrolled case, we had to construct several base cases to provide a direct comparison. We felt that the best way to illustrate the benefits of this control would be to construct three separate base cases - two high use cases, to mimic the same load as the heavy controlled cases discussed earlier, and one lower use case to demonstrate how timing optimization could allow users to use more energy and still save money compared to lower use cases. In the high use simulations, we used the full day load discussed earlier: running the dishwasher once, the washer twice, the dryer twice, and charging the car. In the low use simulations, we showed users only running the dishwasher once and charging the car each day. We did not include the house battery in these uncontrolled cases as there would be no direction about when to discharge or charge the battery. In all of these cases, we distributed appliance use by considering ‘typical’ use hours. For instance, in most cases, people run their dishwashers after dinner - so we restricted our options for running the dishwasher to between 5 and 10 pm. Similarly, we restricted the car to being plugged in after work and before bed, anywhere from 5 pm to 2 am. Washers and dryers were not restricted quite as much as many households run them unpredictably, essentially running them when they need clothes. In all of these base cases, we used the same summer base load and solar values as used in the summer heavy load simulation discussed earlier.

Light Load Base Case

This base case was designed to illustrate the price to a household with time-of-use rates if they did not use much energy comparatively - using 96.18 kWh of energy each day - but still being more expensive than the heavy use controlled case during the summer. The resulting energy use curve for this potential outcome is shown below in figure 15.

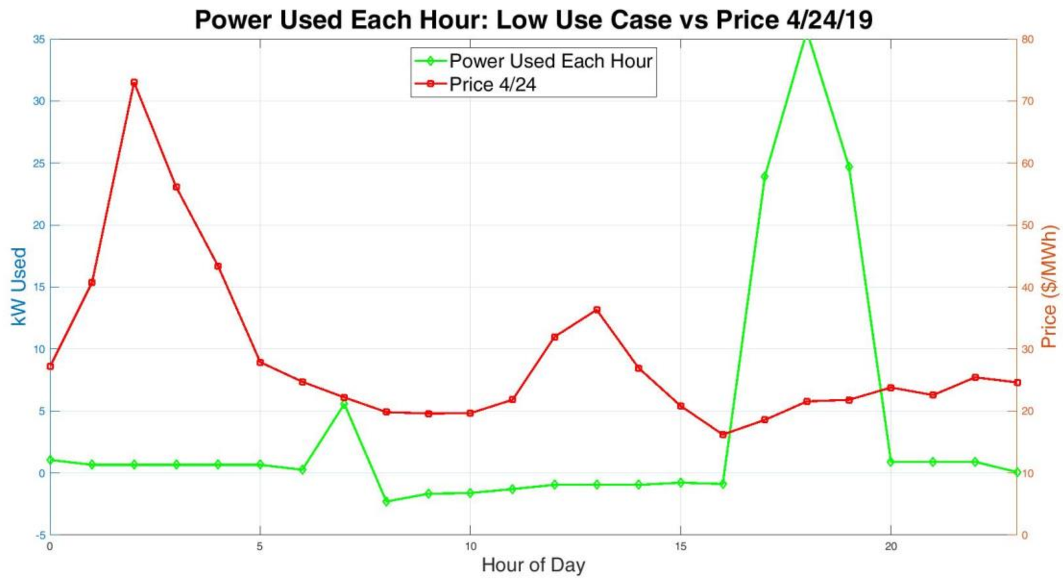

Figure 15: Light Load Base Case

As can be seen in the graph above, energy use is concentrated during the evening hours, after everyone has gotten home from work on a typical day. In this case, the appliances used during these hours are the dishwasher and car charging system. Notably, the typical use times we selected actually worked out quite well in this particular case. The energy use of the house is concentrated during some of the lowest priced hours of the day, resulting in a fairly efficient base case. The cost of this base case energy use comes out to $1.88 per day, or $56.31 per month (assumed here to be 30 days straight with this load distribution).

Heavy Load Base Case: Lucky Distribution

This base case was designed to simulate the price to a household with time-of-use rates if they were both uninformed about their pricing curves and fairly lucky about when they ran their appliances during reasonable hours. The resulting energy use curve is shown below in figure 16.

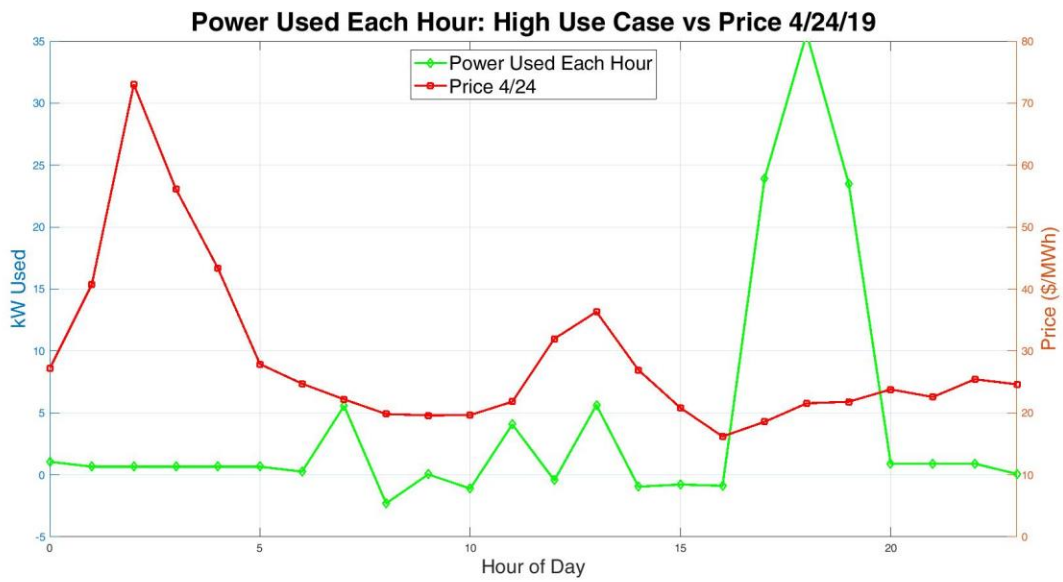

Figure 16: Heavy Load Base Case

Similarly to the previous case, this load distribution has energy use concentrated in the evening, the car charging in the later evening after people get home from work, but the appliances run during the day. The appliances run here are identical to those run in the heavy load simulations run before - two washers, two dryers, a dishwasher, and the car charger. The total cost of this energy usage given the price curve in the graph above comes out to $2.27 per day, or $68.00 per month.

Heavy Load Base Case: Worst Case Distribution

This base case was designed to simulate the price to a household with time-of-use rates if they were both uninformed about their pricing curves and incredibly unlucky about when they ran their appliances during reasonable hours. While this is not a true worst-case scenario, as we stuck to our 'typical' hours, it serves to illustrate a point about how costly uninformed energy use can be with time-of-use pricing. The resulting energy use curve is shown below in figure 17.

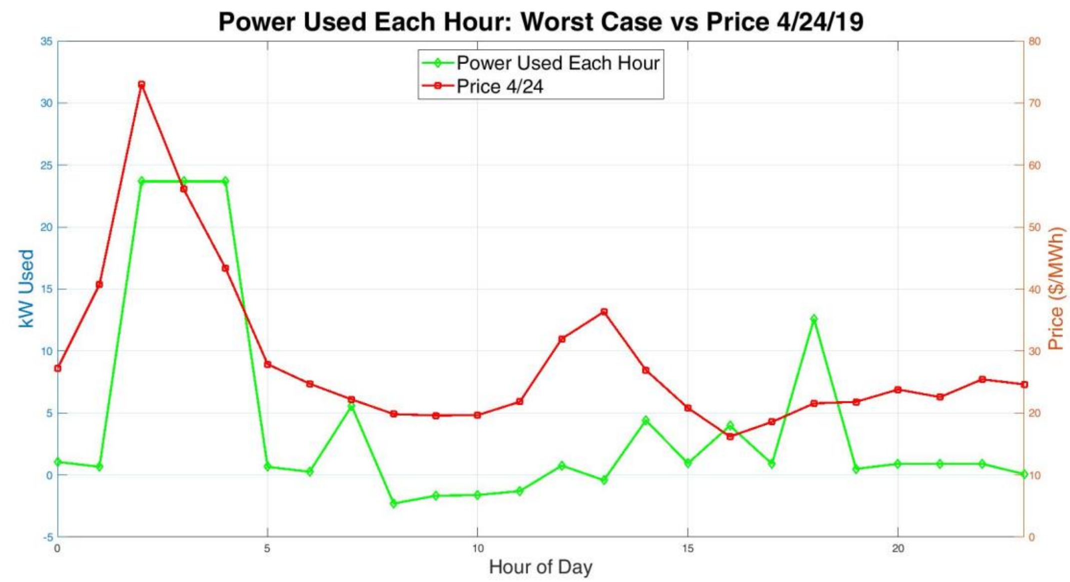

Figure 17: Heavy Load Worst Case

In this case, we concentrated energy use at the worst possible times within our designated 'typical' hours, meaning that the car charged from 2 to 4 am, and that the other appliances ran during the evening near relative peak times. We again ran the washer twice, dryer twice, dishwasher once, and charged the car, mimicking our heavy load from before. The effect of these changes on the price of energy use for the house was massive, resulting in an energy bill totaling $4.72 per day, or $141.85 per month.

Savings

In each of the above heavy load cases, we see significant savings with MyHouse optimization. While the low use case is slightly cheaper than the MyHouse optimized cost, this difference is not nearly as stark as the difference in energy use of each case. These cost comparisons can be seen in table 2.

Table 2: Savings Compared to MyHouse

Case	Daily Cost	Monthly Cost	Savings
Optimized: Summer	$1.97	$59.19	-----
Base: Light Load	$1.88	$56.31	-$2.88
Base: Heavy Load	$2.27	$68.00	$20.52
Base: Worst Case	$4.72	$141.85	$94.37

As seen in the table above, MyHouse optimization has significant effects on the cost of energy to the user - saving users money in all of our heavy load base cases. Furthermore, the cost comparison of the heavy load optimized case to the light load case reveals that despite using significantly more energy, the optimized case has nearly the same cost. These results, particularly the stark differences between optimized and non-optimized heavy load cases, indicate that we have achieved our goal of minimizing energy cost to the user.

III. Ethical Analysis

Ethics

One of the most important aspects of MyHouse is its strong ethical backing. When creating our project, our two main goals were to help California reach its goal[21] of using completely renewable energy by the year 2045, and to help consumers save money. In order to accomplish these goals, we set out to see a way in which we could both have an impact on the duck curve.

The duck curve is shown in figure 18 and shows both the net demand and actual demand.

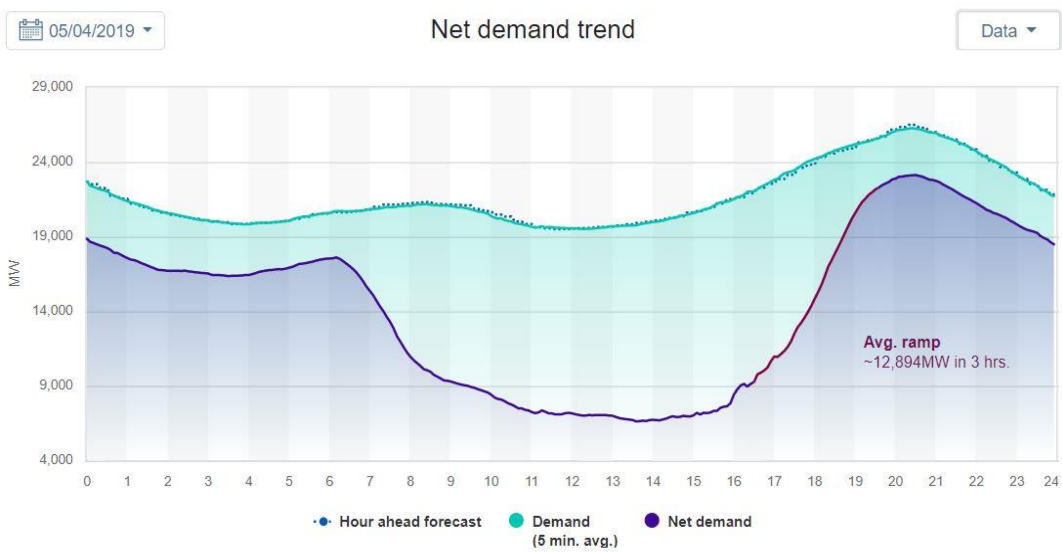

Figure 18: The Duck Curve[22]

The net demand is calculated by accounting for solar power during the day which cannot supply power when the sun is down. This creates a very steep ramping up in demand as the sun begins to go down. This demand continues to increase due to the fact people are come home from work at this time and begin to run all of their appliances before going to bed. This forces utilities to start spinning generators in order to match the level of load that is going to be reached during the night

[21] P. Rogers and K. Murphy, "California mandates 100 percent clean energy by 2045," *The Mercury News*, 10-Sep-2018. [Online]. Available: https://www.mercurynews.com/2018/09/10/california-mandates-100-percent-clean-energy-by-2045/. [Accessed: 04-Jun-2019].

[22] "Net Demand Trend," California ISO - Todays Outlook, 04-May-2019. [Online]. Available: http://www.caiso.com/TodaysOutlook/Pages/default.aspx. [Accessed: 09-May-2019].

time, meaning that they will be using fuel power generators while the generators are essentially unplugged. This means that we are wasting a lot of fuel and generating more fuel emissions that we aren't even directly benefiting from.

We decided that the only way to have a meaningful impact on the duck curve is by getting residents to shift their load. In a study that looked at over 62 pilot programs involving studying the duck curve in California, one of the main questions that arose was whether or not Californians were aware enough about their energy usage in order to make a change[23]. MyHouse directly attacks this issue by informing the user of when energy is the most expensive and advising them as to when to run their appliances in order to save money. Currently, utility pricing does not match the duck curve, but it is hopefully going to be used by the year 2020. If that happens, then the solution that we developed will help to solve a societal dilemma of pollution by motivating the users to cut cost, creating a win-win situation for both the environment and the user.

In the actual design process, we had relatively few ethical issues come up. While there are ethical issues with dictating users' energy use to them, and depriving them of the ability to use their appliances when they want to, there is little ethical danger in merely making energy use recommendations and allowing the user to decide whether or not to follow those recommendations. With MyHouse, we are not actually forcing anyone to do anything, nor could this product be used negatively in a forceful manner. Our sole aim through this project was to provide a benefit to users and society. We believe we have done that without opening the door to major ethical issues.

Furthermore, we had no ethical issues surrounding testing or other design processes. MyHouse is primarily a software that people interact with, and we only tested it on ourselves, thus minimizing any potential ethical issues with testing procedure. Additionally, we shied away from any recording of user inputs or location data, meaning that we have no privacy concerns at this point. Some future work, for instance the mobile app, could potentially have these privacy concerns, as it would need to know home location and typical appliance use patterns for the consumer in order

[23] H. K. Trabish, "California utilities prep nation's biggest time-of-use rate rollout," *Utility Dive*, 06-Dec-2018. [Online]. Available: https://www.utilitydive.com/news/california-utilities-prep-nations-biggest-time-of-use-rate-roll-out/543402/. [Accessed: 04-Jun-2019].

to fulfill its purpose. This data could theoretically be abused, but in the current stage MyHouse is operating in, there is no issue with privacy.

The consideration of these factors in the design process highlighted for us how essential ethical analysis is to engineers - it would have been easy to make errors with testing protocol or data retrieval that led to ethical dilemmas. However, as we undertook this analysis early in the project and considered further steps intentionally, we were able to avoid this.

Sustainability

One of the other primary focuses of our senior design project is to be as sustainable as possible. We are working on creating a home energy management system to help users reduce their peak voltage consumption as well as save money while doing this. However, in our quest to help users of our product save money and use less energy, we need to focus on how the products we use in our home energy management system are sustainable. In our project we need to identify the embodied energy and greenhouse gases associated in the batteries and the use of solar panels.

One of things we want to make our system to do is to store power on a battery to be used later. This will help eliminate the need for the grid even more because we can store solar power into the battery. In theory, this makes us far less dependent on coal, which produces plenty of toxic emissions. With that being said we do encounter an issue from the production of batteries. Creating lithium ion batteries produces a significant amount of carbon dioxide. In a comparison of conventional cars compared to electric vehicles, it was discovered that creating the lithium ion battery releases 74% more carbon dioxide into the air than a conventional car does. While driving an electric vehicle is significantly better from a user standpoint and their carbon footprint goes down drastically, the companies making said battery are releasing a significant amount of carbon dioxide into the air.

In the process of making solar panels, a lot of fossil fuels are burned. Burning fossil fuels leads to the emission of greenhouse gases. This includes producing a lot of carbon dioxide. The production of carbon dioxide is very negative towards the well-being of the planet. However, it creates less of a need to use fossil fuels within homes due to the ability to power products with solar cells, so there still is plenty of benefits towards using it. As photovoltaic technologies advance, we may encounter different issues with other elements. One of the more promising developments uses cadmium telluride, which is one of the worst heavy metals. However, the production of cadmium telluride cells produces significantly lower toxic emissions than what is produced from a coal power plant.

Potential modification we could make to the project is to eliminate the additional battery to store power. While it offers financial benefits, it is not worth making the production of these powerful lithium batteries a common practice. We also feel that we should look more into the solar panels using cadmium telluride. While we will not be able to physically test on these types of solar panels due to lack of availability, we can use them in the simulation of our product and see how efficient they are. Comparing their efficiency to the efficiency of a regular solar panel will enable us to see if this has long term potential towards being used.

One place people are able to recycle electronics is at Green Citizen. Green Citizen will refurbish, resell, or dismantle all electronic products given to them. They also make a point to properly dispose of products they are not able to fix. If they cannot fix it they send products to other approved local vendors to properly dispose of. Sending the broken beyond repair eWaste to local vendors helps eliminate travel costs and prevents e-waste from being shipped across the seas.

The other place people recycle electronics at is TDR Electronic Recycling. They receive products and immediately try to determine whether it can be reused or if it needs to be recycled. If something needs to be recycled, they send the product to have the metals recovered from it. This demanufacturing of components allows for a significant amount of metal to be recovered and potentially used in a different product. In conclusion our project will strive for sustainability because it is important to protect the environment.

Professional Issues and Constraints

When creating MyHouse, the most important constraint that we were faced with was ensuring that our product would not be intrusive in the lives of its users. If we were able to completely control the electronics and the appliances in someone’s house, we would be able to do a much better job in terms of saving the user money and addressing the problems with the duck curve. However, doing so would result in a lot of inconvenience to the users creating unhappiness as well as making it so that no one would want to implement the MyHouse product into their homes making it so that MyHouse would not get the opportunity to solve the problems it was created to address.

If we were given more time and the opportunity to make MyHouse a final product, we would make it so that the user always has the last word on the running of appliances so that MyHouse does not cause them any inconvenience. This would be achieved through the fact that if the user were to physically attempt to operate an appliance, MyHouse would not prevent the appliance from running in any way.

An additional consideration to be made is that when it was created, MyHouse was intended to work in a home with smart appliances, solar panels, battery storage, as well as with an electric vehicle. The issue with this is that only wealthy people would be able to fully benefit from MyHouse because they are the only people that would be able to afford things such as smart appliances and solar panels. MyHouse would need to be made more accessible to the common consumer and those who may be struggling financially. If anything, MyHouse would be very helpful to those who struggle financially because for them money is scarce, and it would help them reduce spending on their electricity bills. A solution to benefit the middle-class and those who face financial difficulty is discussed later on in this paper.

IV. Further Research

Our system also has three primary avenues for expansion and for potentially impactful innovation. First, we could implement automatic read-in from the internet. This would allow MyHouse to automatically retrieve pricing data without us needing to update its pricing curves manually. This would help to take MyHouse from a proof-of-concept of the scheduling idea, to a functionally usable control system for the average consumer. Second, we could create an app using our program to increase the accessibility of this cost-minimizing information. For many families, their electricity bill takes up more of their monthly budget than it ought to – making this accessible to anyone with a smartphone and an internet connection could potentially help millions of people to save money and have more to spend on the rest of their lives. Third, our system could be completed and implemented into a smart home system using Zigbee to control various smart appliances. We have implemented our system on a Raspberry Pi 3 and have the potential to use that to control smart appliances directly, creating a full home control system with minimal user input.

Automatic Read-In from Internet

As it currently stands, MyHouse is manually fed downloaded Excel files containing pricing data from CAISO, a clear limitation for our program. Without the ability to fetch its own pricing data, MyHouse would be extremely clunky for the average consumer, relying up on the user to manually find the pricing curve for the day, download it, change the name of the file to a specific preset name, move it into the proper file and path on a shared drive that MyHouse could access, then go through the normal user actions required to use MyHouse. This is clearly far too much to ask from any consumer, thus we recommend that this is the first avenue of further research addressed in the future. Without this ability to self-update and keep with pricing trends, MyHouse becomes essentially useless as a consumer product – unable to find the correct hours of the day to schedule appliances as it has inaccurate pricing data.

In addition to maintaining its basic functionality, a potential self-updating ability for MyHouse would open many additional avenues for improved systems. With this automatic read in of prices, we could potentially update prices real time, rather than using the published day-ahead projections

– providing truly accurate price calculations for consumers and adjusting appliance scheduling to account for unexpected spikes in pricing.

Mobile App

One of the major ethical issues currently seen in the energy industry is that of inequitable pricing of electricity. As almost everyone is billed based on the same basic guidelines, one can expect the energy bills of most people using equal amounts of energy to be roughly the same – regardless of their household income or their ability to cut their energy usage. This leads to a situation where lower income families pay a significantly larger portion of their monthly take-home pay than wealthier families simply to power their lives. Additionally, wealthier families have a variety of tools to cut their energy consumption: smart thermostats, newer, more efficient appliances, and solar panels and batteries. But lower income families have limited access to many of these energy and money saving innovations, severely constricting their ability to minimize their energy bill.

In light of this, perhaps the most exciting avenue for further work that the MyHouse prototype makes possible is the development of a mobile app using this software and decision-making protocol, an innovation that would make price-signal following appliance scheduling available to nearly everyone. By democratizing this technology through smartphones, MyHouse could help people from lower income families who pay unsustainable portions of their monthly pay to minimize their electricity bills – potentially for free. While this would not solve the issue of inequitable energy spending between socioeconomic groups as both wealthy and lower income families would have access to this technology, the reduction of energy bills seen with MyHouse optimization could have a major impact on the lives of those who sacrifice meals to keep the lights on.

The mobile app would work by allowing users to access the control algorithm of MyHouse, telling them which hours to schedule their appliances in and allowing them to set delays on their appliances manually. Taking this route eliminates the necessity of smart appliances and allows for further adoption of this technology by widening its potential consumer base.

Fully Configured Smart Home Product

The other primary development route available to MyHouse would be its development into a full-scale smart home control device. By implementing a Bluetooth or WiFi based control protocol, such as Zigbee, MyHouse could directly interface with smart appliances, turning them on and off automatically according to its ideal scheduling. Technologically speaking, this would be the culmination of what MyHouse could potentially be – providing a way for users to seamlessly adjust their appliance usage to follow pricing curves without significantly impacting their lives. This potential avenue minimizes consumer activity, only requiring people to load and unload various appliances which would then run on their own based on user selections.

The most important and interest aspect of this particular route forward is its ability to directly control battery usage and electric vehicle charging. Being able to automatically turn on and off the charging functionalities of these appliances enables some interesting possibilities with the scheduling of charging and discharging hours. As no-one would need to directly interface with the appliance to stop or initiate charging, MyHouse could initiate or halt charging at odd hours of the night and during the day when no-one is around, thus enabling it to avoid local spikes in the price of energy when charging, and truly optimize its discharging peak-shaving potential.

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Appendix

Table 3: Solar Measurements from 2/8/19

hour	CAISO (MW)	% (out of 10682)	Scaled output (kw)
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	40	0.003744617113	0.01881670099
8	2411	0.2257067965	1.134176652
9	7016	0.6568058416	3.300449354
10	8736	0.8178243775	4.109567497
11	8813	0.8250327654	4.145789646
12	8709	0.8152967609	4.096866224
13	8593	0.8044373713	4.042297791
14	8394	0.7858079011	3.948684703
15	7771	0.7274854896	3.655614585
16	6158	0.5764838045	2.896831118
17	2448	0.2291705673	1.151582101
18	107	0.01001685078	0.05033467515
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

Table 4: Solar Measurements from 4/17/19

hour	CAISO (MW)	% (out of 10682)	Scaled output (kw)
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	351	0.03285901517	0.1651165512
8	3996	0.3740872496	1.879788429
9	8287	0.7757910504	3.898350028
10	9882	0.9251076577	4.64866598
11	10357	0.969574986	4.872114304
12	10458	0.9790301442	4.919626474
13	10530	0.985770455	4.953496536
14	10682	1	5.025
15	10652	0.9971915372	5.010887474
16	10107	0.946171129	4.754509923
17	9261	0.8669724771	4.356536697
18	7219	0.6758097735	3.395944112
19	2827	0.2646508145	1.329870343
20	126	0.01179554391	0.05927260813
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

Table 5: Solar Measurements from 8/10/18

hour	CAISO (MW)	% (out of 10682)	Scaled output (kw)
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	222	0.02078262498	0.1044326905
8	2359	0.2208387942	1.109714941
9	5043	0.4721026025	2.372315578
10	6245	0.5846283468	2.937757442
11	7481	0.7003370155	3.519193503
12	8214	0.7689571241	3.864009549
13	8893	0.8325219996	4.183423048
14	8859	0.8293390751	4.167428852
15	8899	0.8330836922	4.186245553
16	8500	0.7957311365	3.998548961
17	7327	0.6859202397	3.446749204
18	5345	0.5003744617	2.51438167
19	2356	0.2205579479	1.108303688
20	357	0.03342070773	0.1679390564
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

Table 6: Solar Measurements from 10/23/18

hour	CAISO (MW)	% (out of 10682)	Scaled output (kw)
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	664	0.06216064407	0.3123572365
9	4417	0.4134993447	2.077834207
10	7449	0.6973413218	3.504140142
11	8139	0.761935967	3.828728234
12	8196	0.7672720464	3.855542033
13	8359	0.7825313612	3.93222009
14	8397	0.7860887474	3.950095956
15	8047	0.7533233477	3.785449822
16	7561	0.7078262498	3.556826905
17	5056	0.4733196031	2.378431005
18	1400	0.131061599	0.6585845347
19	64	0.005991387381	0.03010672159
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0

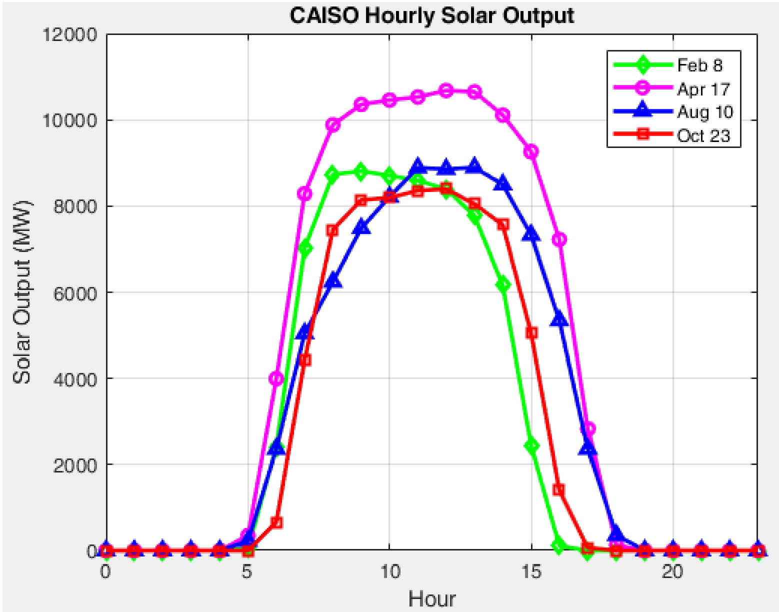

Figure 19: CAISO Hourly Solar Output

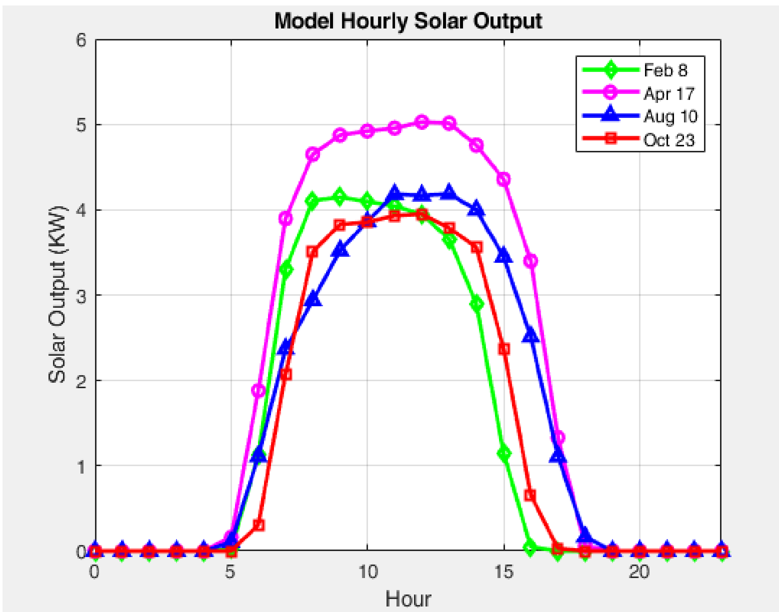

Figure 20: Model Scaled Hourly Solar Output

Table 7: Hourly HVAC Energy Consumption for 2/8/19

hour	Power used (kW)
1	1.603
2	0.8942
3	0.8966
4	1.201
5	1.201
6	1.201
7	1.201
8	1.199
9	0.8958
10	0.8926
11	0.5927
12	0.8853
13	0.5897
14	0.8918
15	0.5918
16	0.8922
17	0.8943
18	0.8943
19	0.895
20	1.193
21	0.8943
22	1.197
23	0.8985
24	1.198

Table 8: Hourly HVAC Energy Consumption for 4/17/19

hour	Power used (kW)
1	1.292
2	0.5934
3	0.8921
4	0.8917
5	0.8919
6	0.891
7	0.5931
8	0.5907
9	0.5868
10	0.2913
11	0
12	0
13	0
14	0.2986
15	0.4009
16	0.5034
17	0
18	0
19	0
20	0.2921
21	0.2925
22	0.2934
23	0.588
24	0.5877

Table 9: Hourly HVAC Energy Consumption for 8/10/18

hour	Power used (kW)
1	0.6903
2	0.2917
3	0.2919
4	0.292
5	0.2917
6	0.2917
7	0
8	0
9	0
10	0.2996
11	0.3061
12	0.6244
13	0.6308
14	0.8471
15	0.7299
16	0.6282
17	0.6214
18	0.3061
19	0.3013
20	0.295
21	0
22	0.2953
23	0
24	0

Table 10 : Hourly HVAC Energy Consumption for 10/23/18

hour	Power used (kW)
1	1.292
2	0.5925
3	0.887
4	0.5901
5	0.5883
6	0.2983
7	0.5876
8	0.2936
9	0.586
10	0.2914
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0.2911
19	0.2923
20	0.2929
21	0.5865
22	0.2937
23	0.5893
24	0.8862

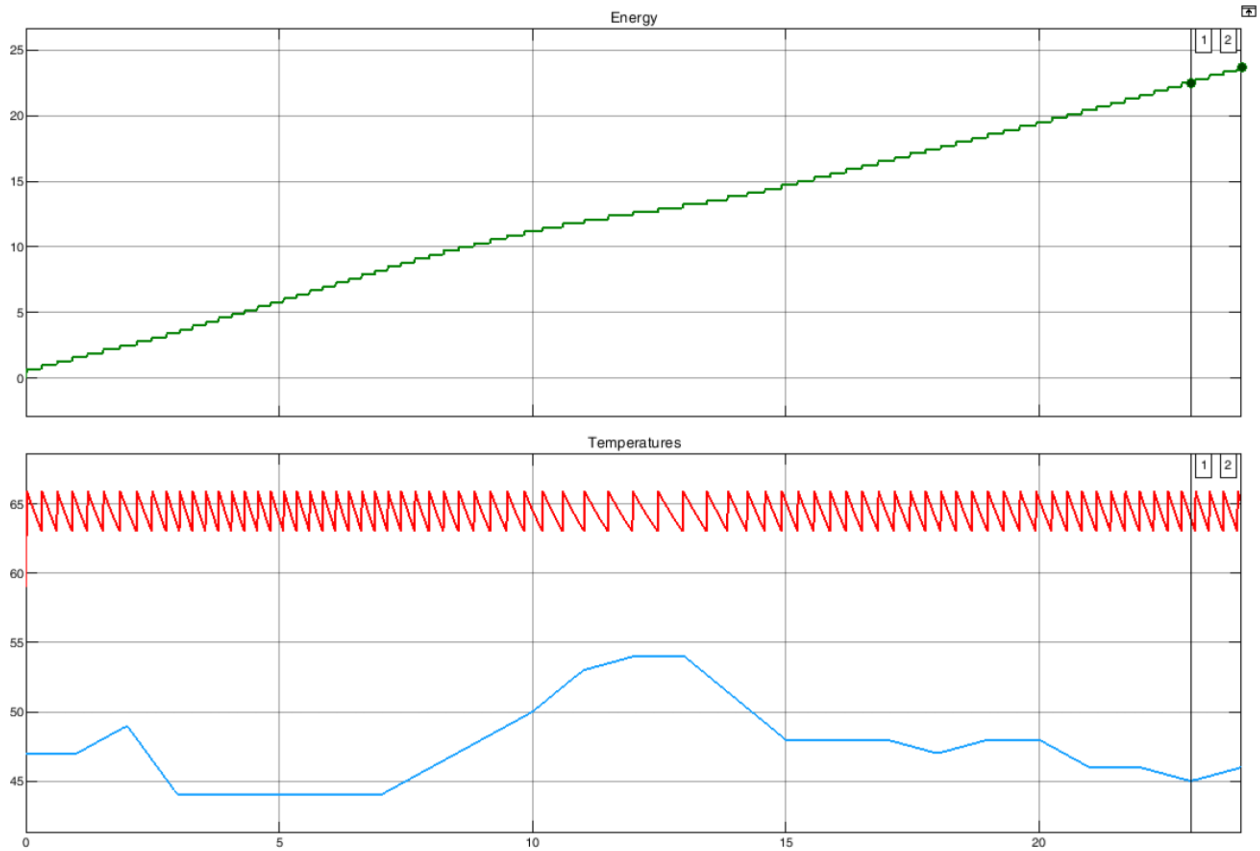

Figure 21: Winter energy and temperature 2/19/19

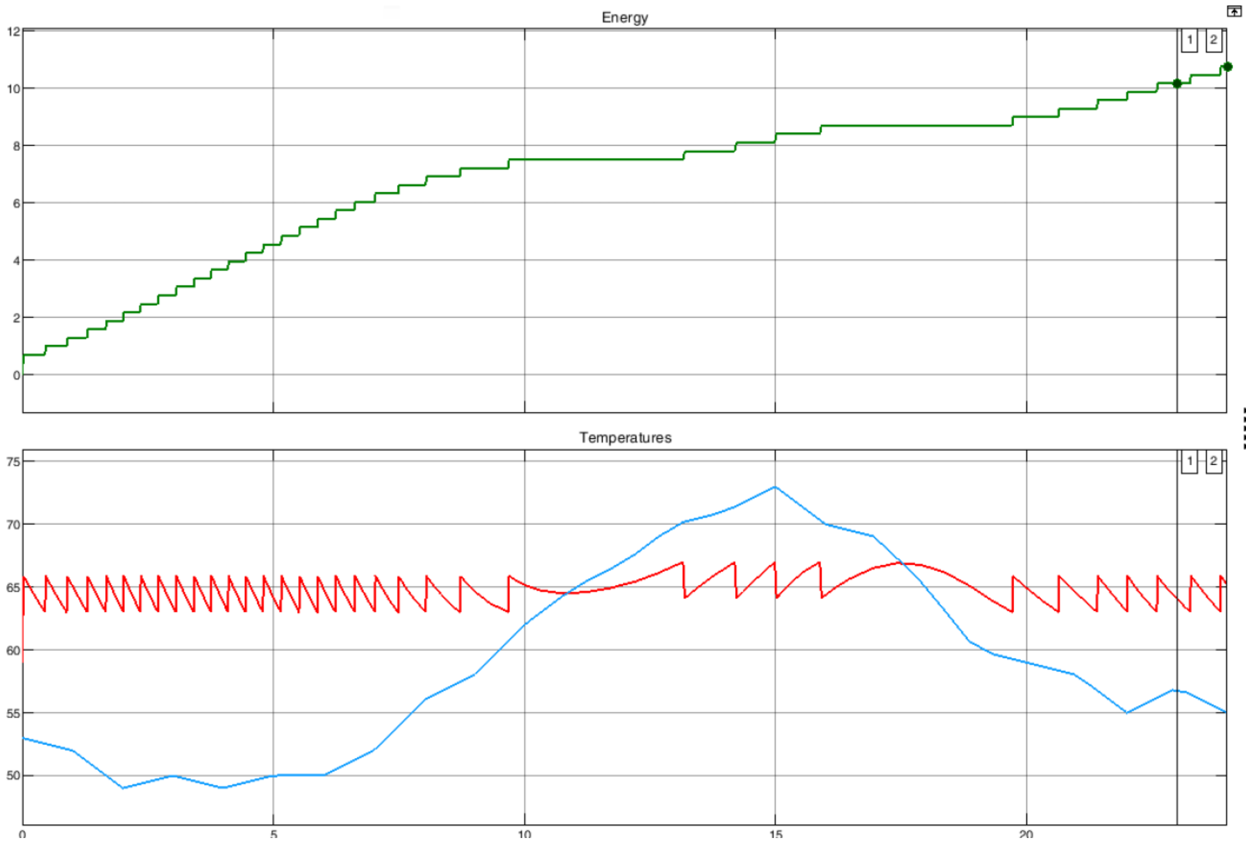

Figure 22: Spring energy and temperature 4/17/19

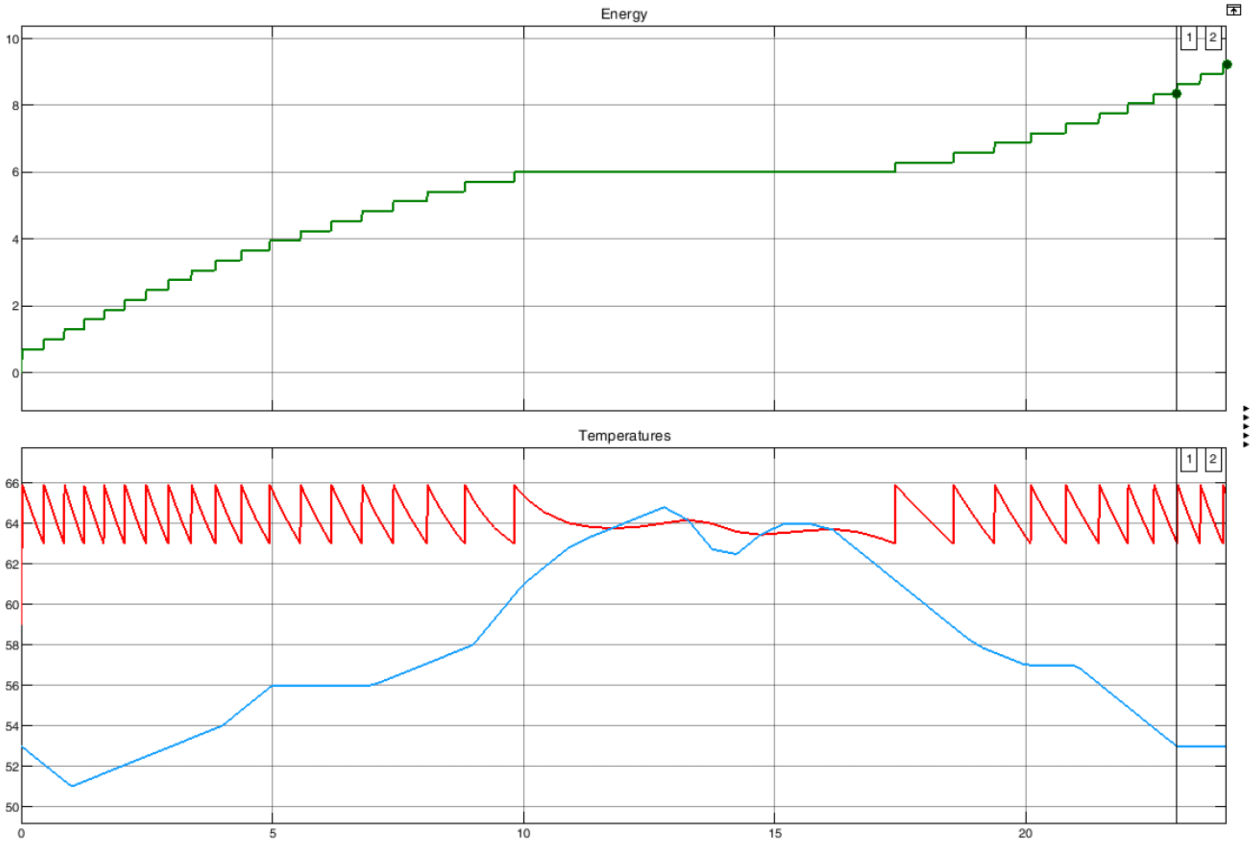

Figure 23: Fall energy and temperature 10/23/18

Table 11: Appliances Used Each Hour to Create Base Load

hour	appliances used
1	refrigerator
2	refrigerator
3	refrigerator
4	refrigerator
5	refrigerator
6	refrigerator
7	refrigerator
8	refrigerator, electric range, hair dryer, toaster, coffee machine
9	refrigerator
10	refrigerator
11	refrigerator
12	refrigerator
13	refrigerator
14	refrigerator
15	refrigerator
16	refrigerator
17	refrigerator
18	refrigerator, television
19	refrigerator, television, electric range
20	refrigerator
21	refrigerator, television
22	refrigerator, television
23	refrigerator, television
24	refrigerator, television

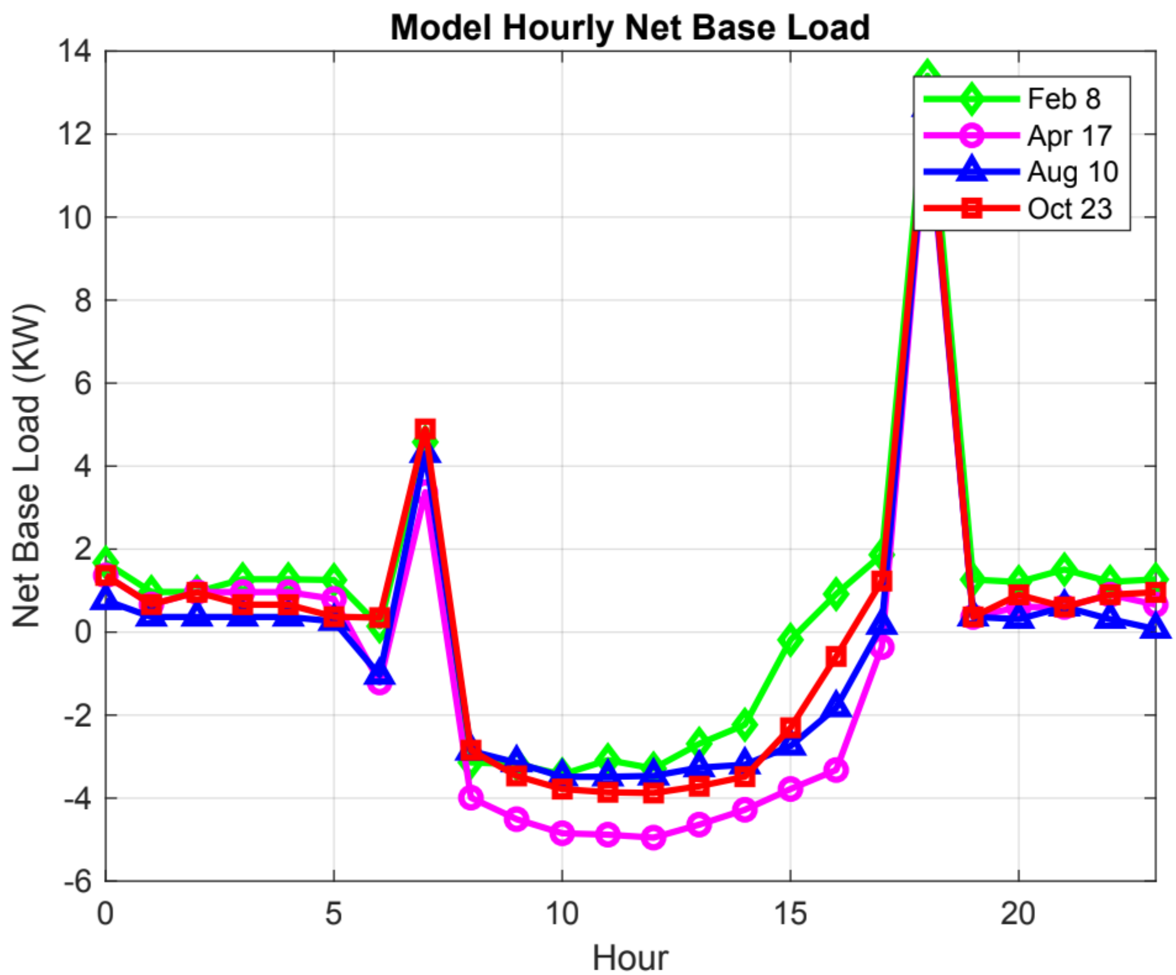

Figure 24: Base Load Factoring in Solar Energy Production, HVAC, and Home Appliances

Appliance Priority Switch Statement from MyHouse Code

```
%% Reading in things to run

m = 1;
i = 1;
j = 1;
n = 24;
indicator = 0;


while j ~= 0
    j = input('\nPlease select appliances to run today in order of
priority \n1 for Washer, 5 for Dryer, 9 for Dishwasher, 11 for Charging
Car, 13 for Charging Battery, 15 for Discharging Battery \nWhen finished,
enter 0: ');
```

```
    if j < 0
        disp('Error, invalid input')
    elseif j == 0
        break
    elseif isnan(j) || fix(j) ~= j
        disp('Please enter an integer')
    else
        switch(j)
            case 1
                while indicator == 0 && m < 25
                        if (apprun(m)+ Wash(1)) <= Effmode
                            apprun(m) = apprun(m) + Wash(1)/2;
                            indicator = 1;

                        else
                            m = m + 1;
                            if m == 25
                                apprun(m)=apprun(m)-sun(m);
                                disp('Could not run appliance under
efficiency mode, appliance not ran')
                            end
                        end
                end
                indicator = 0;
                m = 1;

            case 5
                 while indicator == 0 && m < 25
                        if (apprun(m) + Dry(1)) <= Effmode
                            apprun(m) = apprun(m) + Dry(1);
                            indicator = 1;
                        else
                            m = m + 1;
                            if m > 24
                                disp('Could not run appliance under
efficiency mode, appliance not ran')
                            end
                        end
                 end
                indicator = 0;
                m = 1;

            case 9
                 while indicator == 0 && m < 25
                        if (apprun(m) + Dishwash(1)) <= Effmode &&
(apprun(m+1) + Dishwash(1)) <= Effmode
                            apprun(m) = apprun(m) + Dishwash(1);
```

```
                            apprun(m+1) = apprun(m+1) + Dishwash(1);
                            indicator = 1;
                        else
                            m = m + 1;
                            if m == 25
                                apprun(m)=apprun(m);
                                disp('Could not run appliance under
efficiency mode, appliance not ran')
                            end
                        end
                end
                indicator = 0;
                m = 1;

            case 11
                while indicator == 0 && m < 22
                   x = CARSOC * 60;
                   y = CARSOC * 60;
                   h = [0;0;0;0];
                   s = [0;0;0;0];
                   q = 0;
                   prev = CARSOC;
                   while (x + 20 * 0.869) < 60 * 60 * .9
                       min = 0;
                       while min < 60 && (x + 20 * 0.869) < 60 * 60 * .9
                           x = x + 20 * 0.869;
                           y = y + 20;
                           min = min + 1;
                       end
                       h(q + 1) = (y / 60) - prev;
                       s(q + 1) = (x / 60) - prev;
                       q = q + 1;
                       prev = x / 60;
                   end


                   if (apprun(m) + h(1)) <= Effmode && (apprun(m+1) +
h(2)) <= Effmode && (apprun(m+2) + h(3)) <= Effmode && (apprun(m+3) +
h(4))
                       for i = 0:1:3
                           apprun(m + i) = apprun(m + i) + h(i + 1);
                           CARSOC = CARSOC + s(i + 1);
                       end
                       indicator = 1;
                   else
                       m = m + 1;
                       if m == 22
```

```
                                disp('Could not run appliance under
efficiency mode, appliance not ran')
                            end
                        end
                    end
                    indicator = 0;
                    m = 1;

                case 13
                    while indicator == 0 && m < 25 % made changes to
accurately reflect that battery is not receiving all of the power
delivered to it from the load.
                        x = SOC * 60;
                        y = SOC * 60;
                        h = [0,0,0];
                        s = [0,0,0];
                        q = 0;
                        prev = SOC;
                        while (x + 5 * 0.948) < 14 * .9 * 60
                            min = 0;
                            while min < 60 && (x + 5*0.948) < 14 * .9 * 60
                                x = x + 5*0.948;
                                y = y + 5;
                                min = min + 1;
                            end
                            h(q + 1) = (y / 60) - prev;
                            s(q + 1) = (x / 60) - prev;
                            q = q + 1;
                            prev = x / 60;
                        end
                        if (apprun(m) + h(1)) <= Effmode && (apprun(m+1) +
h(2)) <= Effmode && (apprun(m+2) + h(3)) <= Effmode
                            for i = 0:1:2
                                apprun(m + i) = apprun(m + i) + h(i + 1);
                                SOC = SOC + s(i + 1);
                            end
                            indicator = 1;
                        else
                            m = m + 1;
                            if m == 25
                                disp('Could not run under eff mode, appliance
not ran')
                            end
                        end
                    end
                    indicator = 0;
                    m = 1;
```

```
            case 15
                while indicator == 0
                    while (SOC - 5 / 60) > 14 * 0.15 && n > 0 &&
apprun(n)>= 0
                        min = 0;
                        while min < 60 && (SOC - (5 / 60)) > (14 * 0.15)
&& (apprun(n) - (5 * 0.948)/60) >= 0
                            min = min + 1;
                            apprun(n) = apprun(n) - ((5 * 0.948) / 60);
                            SOC = SOC - (5 / 60);
                        end
                        n = n - 1;
                    end
                    indicator = 1;
                end
                indicator = 0;
                m = 1;



            otherwise
                disp('Error, Invalid Input');
        end
    end
End
```

MyHouse Hour Assignment Code

```
r = 0;
x = 0;
y = 1;
runorder_times_realhours = [time_po, price_ordered, apprun]; % Format
output - hours from now, price that hour, which appliance is running
runorder_times_fc = [time_pofc, price_ordered, apprun];
runorder_times_hourstied = zeros(24,2);

for r = 1:1:24
    runorder_times_hourstied(r,1) = r - 1;
    for y = 1:1:24
        if r - 1 == time_po(y)
            runorder_times_hourstied(r,2) = apprun(y);
            x = 1;
        else
            y = y + 1;
        end
    end
```

```
    x =  0;
end

for k = 1:1:24
    runorder_times_hourstied(k,2) = runorder_times_hourstied(k,2) +
base(k) - sun(k);
end
```

Hour Sorting Algorithm

```
%% Reading in price inputs

read = 'prices.csv'; %insert downloaded file here. needs .csv
x = xlsread(read, 1, 'O2:O25'); %reads in the prices
y = xlsread(read, 1, 'D2:D25'); %reads in the times
clockhours = zeros(24);
apprun = zeros(24,1);


for r = 1:24 %adjusts the times to be read in as 0-23 hours from current
hour according to the current hour
    if y(r) >= 18
        y(r) = y(r) - 18;
    elseif y(r) < 18
        y(r) = y(r) + 6;
    end
end

clockhours = y;

[time,idx1] = sort(clockhours); %sorts the times in ascending order
sunhours = time;
price = x(idx1); %sorts the prices in the same order as the hours
[price_ordered,idx2] = sort(price); %sorts the prices in ascending order
time_po = time(idx2); %sorts the times in the same order as the prices\
sun_po = sun(idx2);
apprun_po = apprun(idx2);
time_array = [time, price, sun, apprun];
price_array = [time_po, price_ordered, sun_po, apprun_po]; %displays the
hours in order of when prices are lowest


for r = 1:24
    if time(r) >= currenthour
        time(r) = time(r) - currenthour;
    elseif time(r) < currenthour
```

```
        time(r) = time(r) - currenthour + 24;
    end
end


[fromcurrenttime,idx3] = sort(time); %sorts the times in ascending order
pricefc = price(idx3); %sorts the prices in the same order as the hours
[fromcurrentprice,idx4] = sort(price);
time_pofc = time(idx4); %sorts the times in the same order as the prices
sun_fc = sun(idx3);
sun_pofc = sun(idx4);
apprun_fc = apprun(idx3);
apprun_pofc = apprun(idx4);
time_arrayfc = [fromcurrenttime, pricefc, sun_fc, apprun_fc]; %displays
the prices in order of time
price_arrayfc = [time_pofc, fromcurrentprice, sun_pofc, apprun_pofc];
```